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INNOVATIVE THERMAL HAZARDOUS WASTE TREATMENT PROCESSES

by

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This report contains discussions of 21 thermal processes identified by the U.S. Environmental Protection Agency (U.S. EPA) as innovative processes for treating or destroying hazardous organic wastes. The subject processes were identified through two national solicitations for innovative processes and several extensive literature surveys.

Information about the subject processes was provided voluntarily by the process developers. The criteria used for selection of a process for the report included the innovativeness of the process when compared with conventional existing processes and the potential contribution the process could make to the evolving field of hazardous waste management technology.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report discusses 21 new processes for treating and destroying hazardous waste which were found to offer innovative approaches to waste treatment. The information in this report will be useful to those responsible for developing alternative hazardous waste management strategies and to those interested in new waste treatment technology developments.

For further information, please contact the Alternative Technologies Division of the Hazardous Waste Engineering Research Laboratory.

David G. Stephan
Director
Hazardous Waste Engineering Research Laboratory

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The assistance and support of Dr. Forest Mixon, Dr. Wayne Westbrook, and the technical staff of the Research Triangle Institute in compiling information for this report is gratefully acknowledged. Also gratefully acknowledged is the excellent cooperation of the developers of the various systems in providing information to the author for his review.

1.0 SUMMARY

This report contains discussions of 21 thermal processes identified by the U.S. Environmental Protection Agency (U.S. EPA) as innovative processes for treating or destroying hazardous organic wastes. The subject processes were identified through two national solicitations for innovative processes and several extensive literature surveys.

Information about the subject processes was provided voluntarily by the process developers. The criteria used for selection of a process for the report included the innovativeness of the process when compared with conventional existing processes and the potential contribution the process could make to the evolving field of hazardous waste management technology.

No project such as this one can include all innovative processes. A process not being included should not be interpreted as a negative evaluation of that process. It is the Agency's intention to publish other compilations such as this one periodically. Those individuals wishing to have their process included should contact the Alternative Technologies Division, Hazardous Waste Engineering Research Labortory.

A summary of the included processes is contained in Table 1. A compilation of expressed advantages and potential limitations for the subject processes is shown in Table 2.

As the country continues to support the conversion of our hazardous waste processes from those based on land disposal to those based on alternative technologies, processes such as the one reviewed in this report will become more common. This encouraging technology development should further the day when hazardous waste management and disposal is no more a problem.

TABLE 1. PROCESS SUMMARY

Process Name	Description	Waste Streams	State of Development	Test Data Available	Cost Data Available	For Information Contact
Zimpro Wet Air Oxidation	Uses elevated temperature and pressure to oxidize organics in water	Aqueous streams with less than 5% organics	C	A	1	William Copa Zimpro, Inc. Military Road Rothschild, WI 54474 (715) 359-7211
IT Catalyzed Wet Oxidation	Uses selected catalysts and elevated temperature and pressure to oxidize organics	Aqueous waste stream with suspended organics	B	D	3	IT Enviroscience, Inc. 9041 Executive Park Drive Knoxville, TN 37923 (615) 690-3211
MODAR Supercritical Fluid Oxidation	Uses high temperatures and very high pressure to oxidize organic contaminants in water	Aqueous slurries or organic solutions	P	D	3	MODAR, Inc. 14 Tech Circle Natick, MA 01760 (617) 655-7741
Methods Engineering High Temperature Wet Oxidation	Uses long vertical underground tubular reactor to oxidize suspended organics in water	Liquids or sludges	Co	NA	3	Methods Engineering, Inc. P. O. Box 282 Angleton, TX 77515 (713) 331-7268
Battelle Northwest Aqueous Phase Alkaline Destruction of Halogenated Organics	Converts halogenated organics into an oil using mild alkali under pressure	Halogenated liquids and granular solids	B	D	NA	Battelle Pacific Northwest Laboratories P. O. Box 999 Richland, WA 99352 (509) 375-2927
GARD Catalytic Dehalogenation of Hazardous Wastes	Dehalogenizes compounds by replacing halogen atom with hydrogen atom	Liquids with high concentration of halogen compounds	B	D	3	Chamberlain National GARD Division 7501 N. Natchez Avenue Niles, IL 60648 (312) 647-9000
Battelle Northwest Joule Heated Glass Melter	Applies electric current directly to waste material for combustion and for creation of a glass matrix	Soils and other granular mineral matter	P	NA	NA	Battelle Pacific Northwest Laboratories P. O. Box 999 Richland, WA 99352 (509) 375-2927
Penberthy Electromelt Pyro Converter	Uses a bed of molten glass to oxidize organics and to capture ash and inorganics	Any liquid or solid waste stream	C*	NA	2	Penberthy Electromelt International, Inc. 631 South 96th Street Seattle, WA 98108 (206) 762-4244
Battelle Columbus Multisolid Fluidized Bed	Uses a moving bed of heated inert material to incinerate wastes	Granular solids, sludges, slurries, liquid and gases	C*	NA	NA	Battelle Memorial Institute 505 King Avenue Columbus, OH 43201 Attention: Jack Conner

TABLE 1 (continued)

Process Name	Description	Waste Streams	State of Development	Test Data Available	Cost Data Available	For Information Contact
GA Technologies Circulating Bed Waste Incineration	Uses a circulating mass of heated inert material to incinerate waste materials	Solids, sludges, and liquids	C	A, B	1	William Rickman GA Technologies P. O. Box 85608 San Diego, CA 92138 (619) 455-3860
Waste-Tech Services Low Temperature Fluid Bed	Uses granular combustion catalyst and limestone in a fluid bed	Liquids, sludges, slurries, or soils	C	C	2	Waste-Tech Services, Inc. P. O. Box 736 Idaho Falls, ID 83402 (208) 522-0850
Midland Ross Pyrolytic Decomposition	Heats waste materials in the absence of oxygen to drive off volatiles for incineration or recovery	Viscous liquids, sludges, and high ash materials	C	A	NA	Midland-Ross Corporation Energy Technology Division 900 N. Westwood P. O. Box 985 Toledo, OH 43696 (419) 537-6444
Russell and Axon High Temperature Pyrolysis with Oxygen	Uses oxygen induced high temperature to pyrolyze water	Solids and liquids	C*	NA	2	Russell and Axon 319 N. Fourth Street Suite 700 St. Louis, MO 63102-2774 (314) 231-9693
Rockwell International Molten Salt Destruction	Uses a bed of molten sodium carbonate to destroy wastes and scrub acid gases	Low ash, low water content, solid or liquid wastes	P	A	NA	Rockwell International Environmental and Energy Systems Division 8900 De Soto Avenue Canoga Park, CA 91304 (213) 700-8200
Industronics Consertherm Rotary Kiln	A modular controlled air incinerator	Liquids, sludges, or solids	C	B	1	Industronics, Inc. 489 Sullivan Avenue P. O. Box G South Windsor, CT 06074-0956 (203) 289-1551
PEDCo Technology Fast Rotary Reactor	A rapidly rotating cylinder utilizing dryer technology for waste incineration	Solids or sludges	P	C	NA	PEDCo Technology Corporation 11499 Chester Road Cincinnati, OH 45246-1000

TABLE 1 (continued)

Process Name	Description	Waste Streams	State of Development	Test Data Available	Cost Data Available	For Information Contact
IGT "Cyclin" Cyclone Incinerator	A cylindrical shaped combustion chamber provides for intensive mixing of fuel and air	Gases or atomized liquids	C	C	1	Institute of Gas Technology 3424 South State Street Chicago, IL 60616 (312) 567-3650
Thagard High Temperature Fluid Wall Reactor	Uses electrically induced radiant heat to pyrolyze organic contaminants	Granular solids	C	A	2	Thagard Research Corporation 3303 Harbor Boulevard Suite F-4 Costa Mesa, CA 92626
Huber Advanced Electric Reactor	Uses electrical heat to pyrolyze organic materials at extremely high temperatures	Finely ground solids	C	A	1	J. M. Huber Corporation P. O. Box 2831 Borger, TX 79007 (806) 274-6331
Pyrolysis Systems Pyroplasma	Uses plasma arc device to create extremely high temperatures for waste destruction	Highly toxic liquids	P	C	2	Pyrolysis Systems, Inc 4935 Kent Street Niagara Falls, Ontario L2H 1J6 Contact: Mr. Ian Thom
Applied Energetics Plasma Temperature Incinerator	Burns waste in a pressurized stream of preheated oxygen	Liquids and fluidized solid waste	P	C	2	Applied Energetics, Inc. P. O. Box 1177 Tullahoma, TN 37388 (615) 455-0631 Contact: Dr. John B. Dicks

Legend for Table 1

State of Development
C - Commercially available
C* - Commercially available for other than hazardous wastes
P - Pilot scale
B - Lab and bench scale
Co - Conceptual

Test Data Available
A - Sponsored by EPA or other third party
B - Company sponsored tests
C - Company sponsored pilot scale tests
D - Company sponsored bench scale tests
NA - Not Available

Cost Data Available
1 - Based on commercial scale operation
2 - Estimates based on pilot scale operation
3 - Estimates based on bench scale operation
NA - Not Available

TABLE 2. SUMMARY COMMENTS ON PROCESSES

Process	Expressed Advantages	Potential Limitations
Zimpro Wet Air Oxidation	1. Thermally self-sustaining at relatively low organic concentrations 2. Attractive option for dilute toxic waste streams 3. Products of oxidation stay in liquid phase	1. Generally limited to aqueous stream containing nonhalogenated contaminants 2. Not appropriate for solids and very viscous liquids
IT Catalyzed Wet Air Oxidation	1. Catalysts lower oxidation temperatures 2. Catalysts increase the rate of reaction 3. More refractory compounds may be oxidized	1. Addition of catalysts increases costs of process 2. Process best used on a select type of waste, i.e., moderate strength aqueous wastes having high toxicity 3. Process is yet to be demonstrated at pilot scale
MODAR Supercritical Fluid Oxidation	1. Rapid oxidation rates and very short residence times 2. Complete oxidation of organic eliminating need for offgas processing 3. Very efficient removal of inorganic constituents	1. High pressures necessitate sophisticated equipment and operational techniques 2. A continuously operating unit has yet to be demonstrated
Methods Engineering High Temperature Wet Oxidation	1. Pressures are contained by standard tubing 2. Mild steel can be used 3. Process accommodates a wide range of concentration and flow rates	1. The process is still in the conceptual stage 2. Corrosion and fouling of equipment may reduce capacities 3. Permitting of an underground reactor could present problems.
Battelle Northwest-Aqueous Phase Alkaline Destruction	1. Energy recovery in converted oil 2. Reducing conditions minimize oxidative formation of dioxin 3. Based on standard industrial technology	1. Relatively low temperatures may not be sufficient for halogenated wastes 2. Potential suitable waste materials may not be many 3. Interim and supplementary products of the reaction could be more hazardous than original waste stream
GARD Catalytic Dehalogenation of Hazardous Wastes	1. Process retains economic value of materials while rendering them harmless 2. Mild operating conditions, uncomplicated equipment 3. Easily transportable equipment	1. Process has not been demonstrated beyond a bench scale

TABLE 2 (continued)

Process	Expressed Advantages	Potential Limitations
Battelle Northwest Joule Heated Glass Melter	1. Excellent residuals incorporation into glass matrix 2. High retention of heavy metals	1. Electrical energy source may be costly 2. Secondary combustion of offgas may be required
Peberthy Electromelt Pyro Converter	1. Significant volume reductions 2. Residual product is fully stable glass 3. Based on existing glassmaking technology	1. Does not appear appropriate for soils and high ash material 2. Offgas treatment will probably be required 3. Technology is unfamiliar to hazardous waste treatment industry
Battelle Columbus Multisolid Fluidized Bed	1. Safe and economical disposal of waste materials 2. Energy recovery 3. Minimum fuel preparation	1. Temperature excursions may deteriorate the bed 2. May not be suitable for solids incineration
GA Technologies Circulating Bed Waste Incineration	1. Low temperature eliminates ash agglomerization and NO_x emissions 2. Complete combustion to minimize organic emissions 3. Minimal downstream emissions control required	1. Low temperature may limit the process to less refractory waste streams
Waste-Tech Low Temperature Fluid Bed	1. Can effectively handle contaminated soil	1. Effectiveness may be reduced through catalyst removal 2. Extended demonstration is needed
Midland Ross Pyrolytic Decomposition	1. Salts and metals are not liquified or vaporized 2. Reduced particulate emissions 3. Process tends to tie up leachable metals and salt in residue	1. The process appears best suited to a relatively homogeneous waste stream 2. Interim possibly hazardous byproducts should be assessed
Russell and Axon High Temperature Pyrolysis with Oxygen	1. Ultra high temperatures 2. Long residence time 3. No fugitive emissions	1. Use of oxygen increases the cost substantially 2. Generally requires cocombustion with a solid material
Rockwell International Molten Salt Destruction	1. Process destroys waste materials without NO_x emissions 2. Halogens are retained in the salt bed	1. Process is limited to low ash, low water content waste 2. Molten salt can be very corrosive

TABLE 2 (continued)

Process	Expressed Advantages	Potential Limitations
Industronics Consertherm Rotary Kiln Oxidizer	1. Rugged dependable construction 2. Capability of cofeeding liquids, sludges, and solids 3. High turndown ratios	1. Extended demonstration with hazardous wastes is needed
PEDCo Fast Rotary Reactor	1. Reliability and dependability 2. High thermal efficiency 3. Handles wide variety in feed rate	1. Extended demonstration with hazardous wastes is needed
IGT "Cyclin" Cyclone Incinerator	1. Stable and energy efficient combustion 2. Small combustion volume 3. Low temperature combustion	1. Extended demonstration with hazardous wastes is needed
Thagard High Temperature Fluid Wall	1. Reduced residence times 2. Complete destruction of waste materials by virtue of high temperatures 3. Production of medium-Btu combustible gas	1. Input solids must be ground extremely finely
Huber Advanced Electric Reactor	1. Process is very transportable 2. Extremely high treatment efficiencies 3. Essentially no stack or fugitive emissions	1. Input solids must be ground extremely finely
Pyrolysis Systems Pyroplasma	1. Process can handle highly toxic and refractory compounds 2. Scale of equipment is small 3. ON/OFF time cycle of only a few minutes	1. Limited to liquids 2. Demonstration of continued operation is needed
Applied Energetics Plasma Temperature Incineration	1. Process is contained in a very compact unit 2. Combustion reaction increases under these conditions	1. Limited primarily to liquids 2. Demonstration of continuous operation is needed

2.0 INTRODUCTION

This report contains discussion of 21 thermal processes identified by the U.S. Environmental Protection Agency (U.S. EPA) as innovative processes for treating or destroying hazardous organic wastes. The subject processes were chosen through two national solicitations for innovative processes and several extensive literature surveys. The project, for which this document is the final report, also produced much of the information for the alternative technologies section of a 1984 EPA report on incineration issues related to ocean incineration.

While the processes included in the report differ widely in many respects (i.e., waste streams for which they are designed and state of development), they are similar in that they offer innovative approaches to solving problems presented by the generation of hazardous wastes. The reader is cautioned to understand that, while some of these processes have been evaluated by third parties, independent testing of these processes, especially tests under the guidance of the EPA, are the exception rather than the rule. However, all of the processes are considered at least promising. Some of the included processes might be regarded as emerging technologies. Others are in commercial operation and are already well beyond any such categorization as emerging technology.

Information provided in this report is intended to assist in the evaluation of the processes by researchers and others interested in alternative processes for treating and disposing of hazardous wastes. The inclusion of a process in this report should in no way be considered an endorsement of the process by the U.S. EPA. The reader is encouraged to contact the organizations listed in the chapters for more information.

Performance test data have been provided for this report by the process developers; references are given for open literature citations of these data. Where references are not given, the data are from personal communication with representatives of the sponsoring organizations.

The assistance of the technology developers in supplying information and of the technical staff of the Research Triangle Institute in compiling information is gratefully acknowledged.

3.0 OVERVIEW

The processes discussed in this report can be placed into the following generic categories:

Wet Oxidation--processes for oxidizing suspended and dissolved organics in aqueous waste streams. These processes are very effective at detoxifying aqueous waste streams that are too dilute to incinerate economically, yet too toxic to treat biologically. By confining the oxidation to the aqueous medium, wet oxidation does not produce the type or quantity of emissions produced by typical incinerators. The wet oxidation process using the feature of supercritical water is especially innovative in that effective separation of inorganics from the waste stream can be realized in addition to complete oxidation of organics. Wet oxidation does not work as well on chlorinated organics as on many nonchlorinated organics. However, wet oxidation has been used in experimental work to break down chlorinated materials into less hazardous compounds. In general, it is a very promising alternative technology for a common hazardous waste stream, i.e., aqueous wastes containing nonchlorinated toxic organics.

Chemical Transformation--processes that transform the waste streams into other less toxic substances primarily through chemical reactions. These processes are important in that they are examples of technology to encourage resource recovery rather than destruction of wastes. As treatment processes become more the norm than landfills or even than incineration, chemical transformation processes will occupy a much larger segment of the waste management picture. This is especially true for those chemical processes that produce useful materials. Currently, these processes have difficulty competing with conventional disposal methods. However, as disposal costs rise, chemical processes such as the ones discussed in this report will become increasingly attractive.

Molten Glass--processes that use a pool of molten glass as the heat transfer mechanism to destroy organics. The attractiveness of molten glass is based upon the extremely good quality of the residue from the process, i.e., essentially nonleachable glass. The combustion conditions for organics appear to be at least as good as those present in hazardous waste incinerators, and the inorganic residue and ash is incorporated into the glass. Introduction of

this type of technology into the waste management industry, especially for highly toxic organic streams containing toxic metals, could prove very attractive if it can be shown through extraction tests that the residue is nonleachable and may be delistable as a hazardous waste.

Fluidized Bed Incineration--thermal processes using a very turbulent bed of inert granular material to improve the transfer of heat to the waste streams to be incinerated. Advantages of fluidized bed incinerators include their relatively compact design, their relative simplicity of operation, and their ability for combining combustion with pollution control by trapping some gases in the bed. Although fluidized beds have been used for many years in various industries, their use in hazardous waste incineration is still at a demonstration level. It is generally agreed, however, that this approach to waste incineration offers significant potential for the future.

Pyrolysis--processes that break down waste materials into less complex materials through the application of heat in the absence of oxygen. Pyroconversion units are typically custom designed to process specific types of chemicals rather than as multipurpose waste processing units. Consequently, their use as multipurpose hazardous waste treatment facilities has been very limited. However, one of the pyrolysis processes discussed in this report would be suitable for use as a multipurpose waste processing unit. Advantages of pyrolysis processes are that there is a potential for byproduct recovery, that sludge volumes may be reduced without large amounts of supplementary fuel being used, and that air emissions are usually less for conventional incinerators.

Molten Salt--a process in which waste material is injected beneath a bed of molten sodium carbonate for incineration. The process is innovative in that the use of the molten bed requires lower temperatures for waste combustion. Also, the bed acts as a very effective scrubbing medium for acid gases.

Advanced Incinerators--processes that incorporate improvements over conventional incinerators but which maintain the essential principles of conventional incinerators. The report contains three such systems--a liquid injection system incorporating fuel feed to promote extremely intensive mixing and two systems using rotary kilns. These systems are illustrative of the improvements being made in conventional incinerator designs.

Electric Reactor--processes that pyrolyze waste contaminants from particles such as soil through use of an electrically heated fluid wall reactor. These units have been used successfully in other chemical processes and are just beginning to be adopted for waste destruction. The units, especially the portable versions of the processes, appear to offer a very different and potentially valuable thermal option for hazardous waste treatment.

Plasma Systems--processes that use the extremely high temperature of plasma to destroy waste materials. The plasma systems offer a very innovative approach to destroying highly toxic chemicals. Several systems have been researched. Two of these systems are discussed in the report.

4.0 WET OXIDATION

Wet Oxidation--processes for oxidizing suspended and dissolved organics in aqueous waste streams. These processes are very effective at detoxifying aqueous waste streams that are too dilute to incinerate economically, yet too toxic to treat biologically. By confining the oxidation to the aqueous medium, wet oxidation does not produce the type or quantity of emissions produced by typical incinerators. The wet oxidation process using the feature of supercritical water is especially innovative in that effective separation of inorganics from the waste stream can be realized in addition to complete oxidation of inorganics. Wet oxidation does not work very well on chlorinated organics. However, in general, it is a very promising alternative technology for a common hazardous waste stream, i.e., aqueous wastes containing non-chlorinated toxic organics.

The following four wet oxidation processes are included:

Wet Air Oxidation--ZIMPRO, Inc.
Catalyzed Wet Oxidation--IT Corporation
Supercritical Fluid Oxidation--Modar, Inc.
High Temperature Wet Oxidation--Methods Engineering, Inc.

I. TECHNOLOGY: Wet Air Oxidation

DEVELOPER: ZIMPRO, Inc.

II. PROCESS DESCRIPTION AND SCHEMATIC

Wet air oxidation refers to the aqueous phase oxidation of dissolved or suspended organic substances at elevated temperatures and pressures. Water, which makes up the bulk of the aqueous phase, serves to modify oxidation reactions so that they proceed at relatively low temperature (175°-340°C or 350°-650°F) and at the same time serves to moderate the oxidation rates removing excess heat by evaporation. Water also provides an excellent heat transfer medium which enables the wet oxidation process to be thermally self-sustaining with relatively low organic feed concentrations.

An oxygen-containing gas, usually air, is bubbled through the liquid phase in a reactor used to contain the process; thus, the commonly used term "wet air oxidation" (WAO). The process pressure is maintained above the vapor pressure of water and at a level high enough to prevent excess evaporation of the liquid phase, generally between 20 and 200 atm.

The basic flow scheme of a continuous WAO system is shown in Figure 1. A wastewater stream containing oxidizable contaminants is pumped to the system pressure by means of a positive displacement-type pump. The wastewater passes through a heat exchanger which preheats the waste by indirect heat exchange with the hot oxidized effluent. The temperature of the incoming feed is increased to a level necessary to support the oxidation reaction in the reactor vessel. Air and the incoming liquid are injected into the reactor where the oxidation begins to take place. As oxidation progresses up through the reactor, the heat of combustion is liberated, increasing the temperature of the reaction mixture. This heat is recovered by interchanging with the incoming feed. Depending on the temperature of the oxidized effluent following interchange with the feed, final cooling may be required. After energy removal, the oxidized effluent, comprised mainly of water, carbon dioxide, and nitrogen is reduced in pressure through a specially designed automatic control valve.

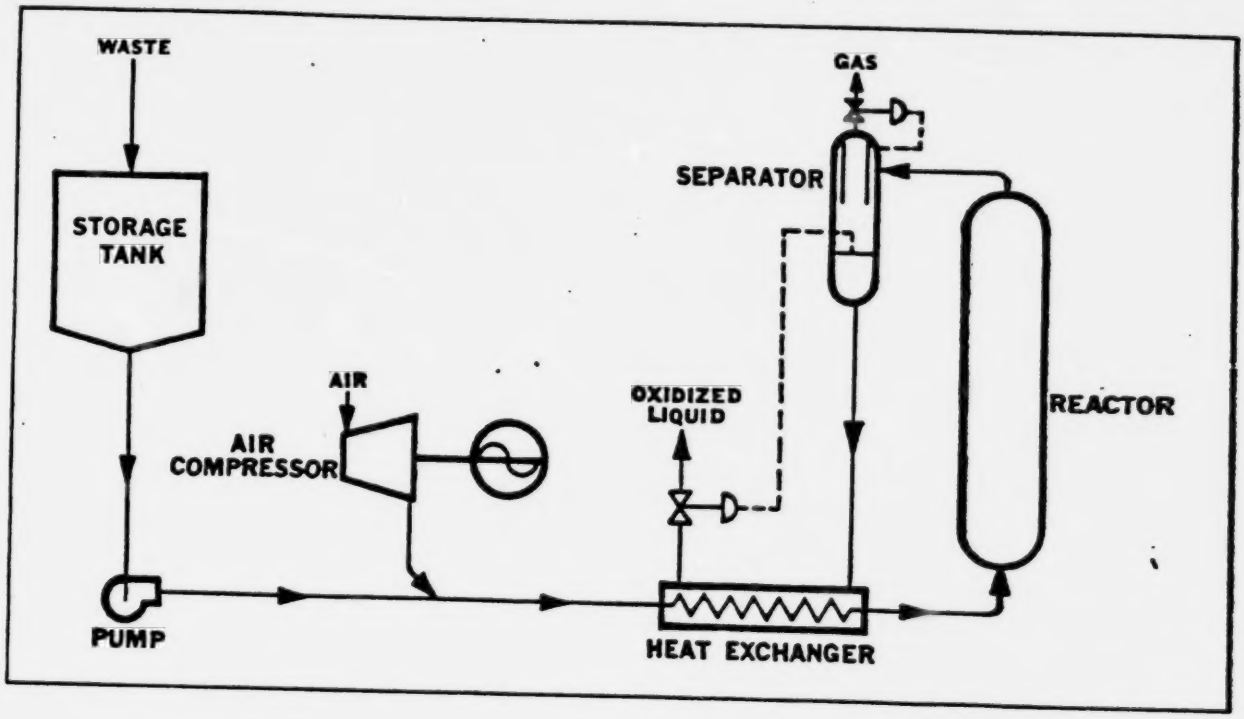


Figure 1. Flowsheet of wet air oxidation process.

Of all variables affecting wet air oxidation, temperature has the greatest effect on reaction rates. In most cases, about 150°C (300°F) is the lower limit for appreciable reaction, about 250°C (482°F) is needed for reaction to the 80-percent reduction of Chemical Oxygen Demand (COD) range, and at least 300°C (572°F) is needed for 95-percent reduction of COD or better reaction within practical reaction time.

Initial reaction rates and rates over the first 30 minutes are relatively fast. After about 60 minutes, rates become so slow that generally little increase in percent oxidation is gained in extended reaction.

WAO can reduce toxicant/contaminants to compounds such as H_2O, CO_2, and various simple acids, depending upon the waste in question. Specific toxic compounds such as the priority pollutants, phenols, cyanides, DDT, nitrosamines, and many carcinogens can be oxidized by WAO. The effluent liquor is suitable for either final discharge or is readily degradable if further biological treatment is desired.

III. ADVANTAGES

The developer states the following:

1. The process is thermally self-sustaining when the amount of oxygen uptake is in the 15-20 grams/liter range.

2. The process is well suited for wastes that are too dilute to incinerate economically, yet too toxic to treat biologically.

3. Condensed phase processing requires less equipment volume than gas phase processing.

4. The products of WAO stay in the liquid phase. Offgases from a WAO system are free of NO_x, SO_2, and particulate. Water scrubbing and, if need be, carbon adsorption or fume incineration are used to reduce hydrocarbon emissions or odors.

5. WAO also has application for inorganic compounds combined with organics. The oxidation cleans up the mixture for further removal of the inorganics. WAO can detoxify most of the EPA priority pollutants. Toxic removal parameters are in the order of 99+ percent using short-term, acute, static toxicity measurements.

IV. OPERATING CONDITIONS

Form of Feed Materials:	Aqueous slurry or solution of organic materials.
Temperature Range:	150°-350°C (300°-600°F)
Pressure Range:	300-3000 psi
Residence Time Range:	15 to 120 minutes
Energy Type and Requirements:	Usually self-sustaining

V. PERFORMANCE TEST RESULTS

Wet air oxidation of a number of classes of wastes has been demonstrated at the Casmalia Resources, Inc. full-scale wet oxidation installation under partial support from the U.S. EPA. The studies included wet air oxidation of pesticide wastes (Canney, 1984a), a solvent still bottoms hazardous waste (Canney, 1984b), phenolic and organic sulfur wastes (Dietrich, 1983a), general organic waste (Dietrich, 1983b), and cyanide wastes (Dietrich, 1983c).

For pesticides (Canney, 1984a), the wet oxidation unit was operated at an average reactor temperature of 280°C (537°F) and a reactor pressure of 1600 psig with a nominal residence time of 182 minutes. Removal of the four pesticides--dinoseb, methoxychlor, carboryl, and malathion ranged from 98.0 percent to >99.8 percent. COD, BOD_5 and DOC removals of 95.3, 93.8, and 96.1 percent were observed.

For the solvent still bottoms, the wet oxidation unit was operated at an average reactor temperature of 268°C (514°F) and a reactor pressure of 1550 psig with a nominal residence time of 118 minutes. COD, BOD, and DOC reductions of 72.3, 73.6 and 47.4 percent were observed.

For the phenolic and organic sulfur wastes, the wet oxidation was operated at an average reactor temperature of 268°C (550°F), a reactor pressure of 1610 psig, and a nominal residence time of 113 minutes. The results show 99.77 percent phenol reduction, 94.0 percent organic sulfur reduction, and 89.3 percent COD reduction (Dietrich, 1983a).

For general organic wastewater, the wet oxidation unit was operated at an average reactor temperature of 277°C (431°F), a reactor pressure of 1550 psig,

and a nominal residence time of 120 minutes. Results showed 90.7 percent COD reduction and 96.7 percent DOC reduction (Dietrich 1983b).

For the cyanide wastewaters, the wet oxidation unit was operated at an average reactor temperature of 257°C (495°F), a pressure of 1220 psig, with a nominal residence time of 80 minutes. Results showed a cyanide reduction of 99.7 percent, a COD reduction of 88.8 percent, and a DOC reduction of 88.4 percent (Dietrich, 1983c).

VI. COST ESTIMATES

Capital: The parameters affecting the installed capital costs of wet oxidation systems are hydraulic flow, amount of oxidation occurring, materials of construction and the severity of the oxidation conditions necessary to meet treatment objectives. These parameters account for the band of capital costs as shown in Figure 2.

Operating: The various operating cost elements and a total operating curve for typical units operating on hazardous wastes are shown in Figure 3. As noted in the figure, power accounts for the largest element of cost. Power is primarily consumed by the air compressor.

While not shown in the figure, auxiliary energy requirements for the oxidation of very dilute wastewaters would be at most 500 Btu/gal. The associated costs for this energy would add 1.5-2.0 cents/gal to overall operating costs.

Total Per Unit of Feed: Expressing total costs, capital plus operating, on a per unit of feed basis requires assumptions on life cycle, depreciation, tax bracket, and current interest rates for the capital cost. One avenue for financing that has been used commercially is leasing. Common lease terms are 5 years and 20 percent value at end of term.* The following table illustrates the effect of hydraulic flow capacity on total costs per unit of feed.

*Assume lease charges based on $17/1000 mo based on total installed cost.

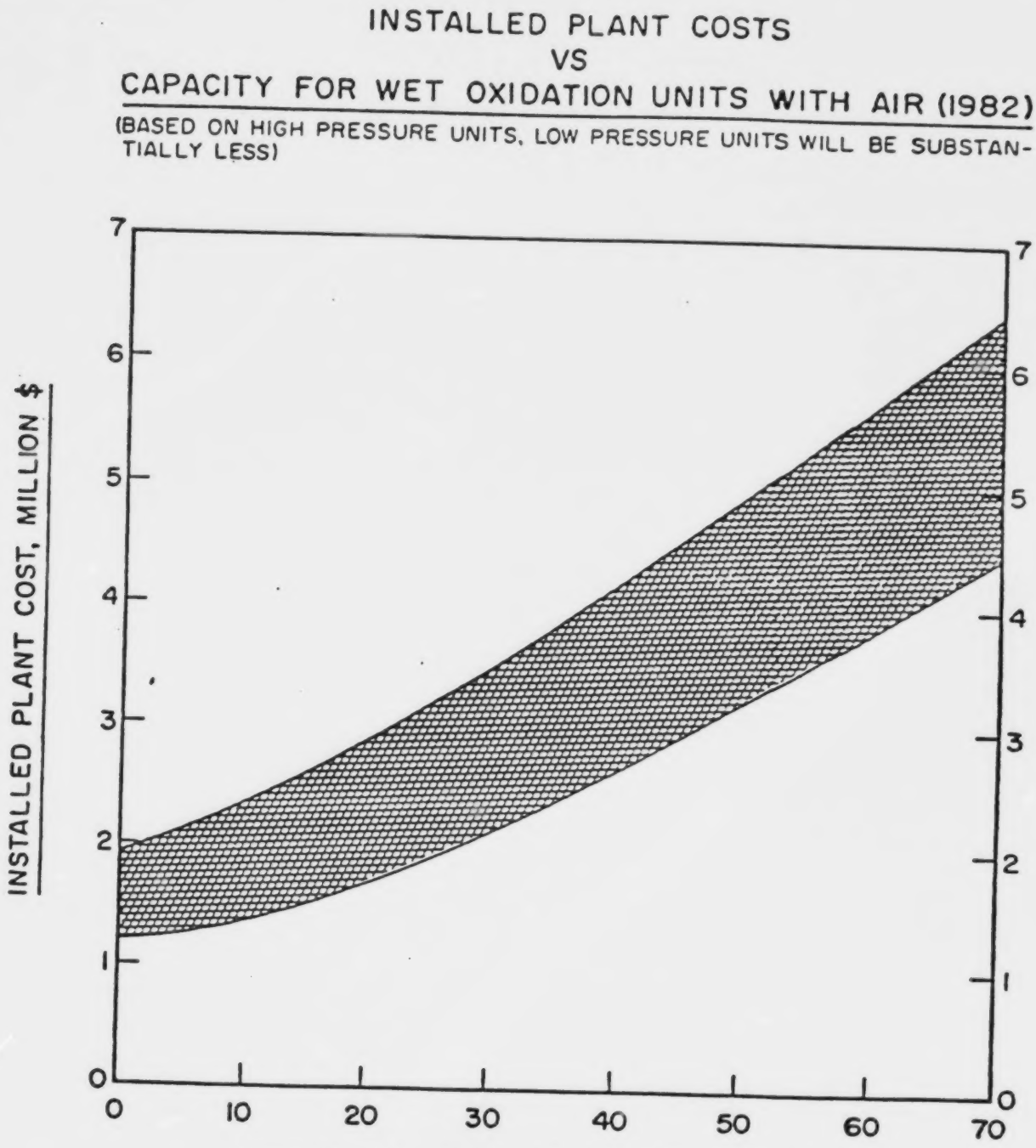


Figure 2. Wet oxidation plant capacity, gpm (U.S.).

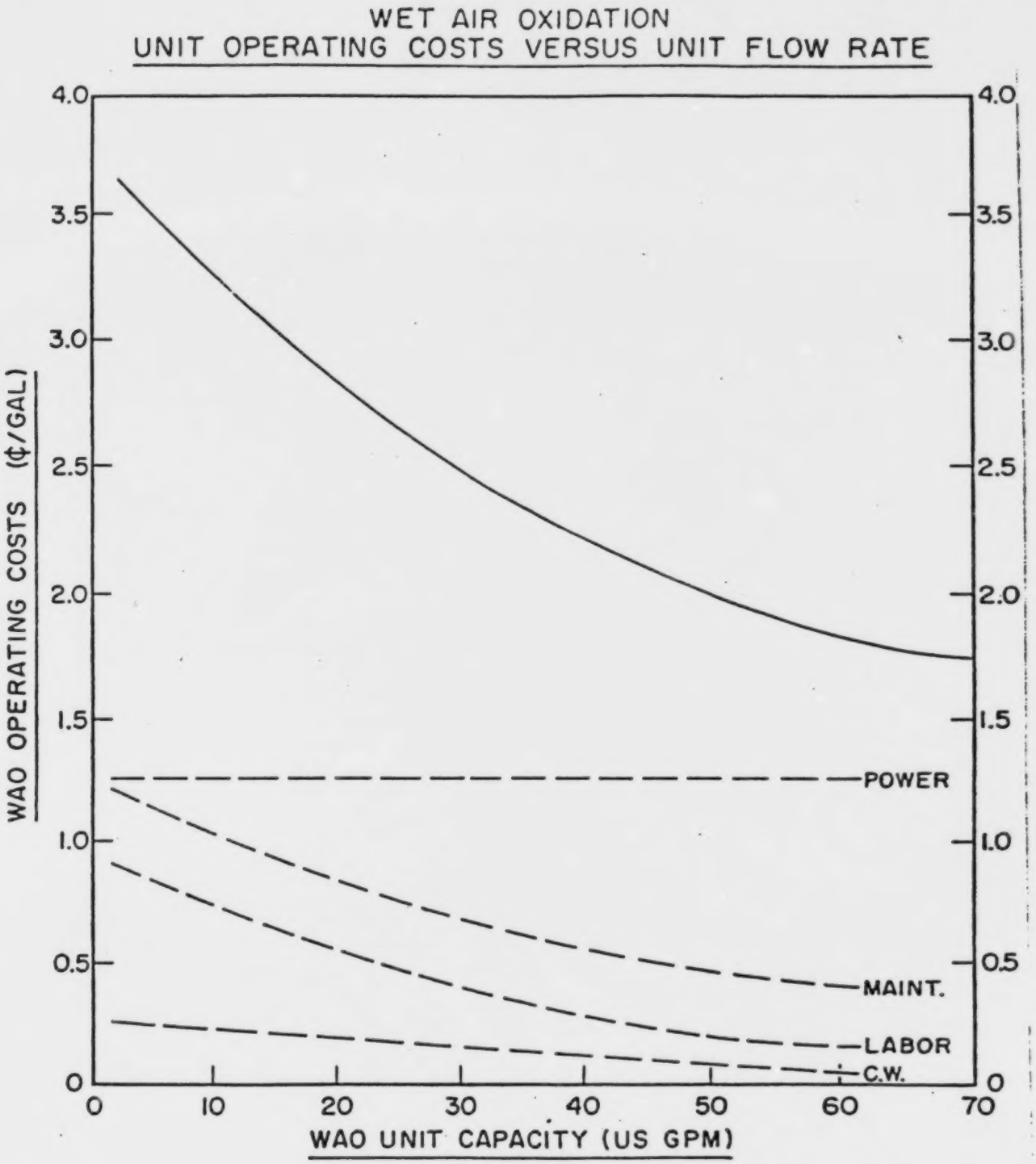


Figure 3. 1982 cost: Power-$0.5/KWH; C.W.-$.10/1000 gallon; maintenance-1% capital cost; labor-$25,000/yr/operator.

Hydraulic Flow (gpm)	Cost Elements per Gallon		
	Operating	Capital	Total
2.0	20	30	50
10	5	7	12
20	3	5	8
40	2-3	4-5	6-8

VII. STATE OF DEVELOPMENT

This process is available at commercial scale. The U.S. EPA and the State of California are supporting a demonstration of a 10 gal/min unit at Casmalia Resources near Santa Maria, California. Other units are operating on hazardous waste at Bofors Nobel in Muskegon, Michigan, and Northern Petrochemical Company in Morris, Illinois.

VIII. FOR MORE INFORMATION

William Copa
ZIMPRO, Inc.
Military Road
Rothschild, Wisconsin 54474
(715) 359-7211

IX. REFERENCES

Canney, P. J. 1984a. Commercial Demonstration of Wet Air Oxidation of Hazardous Wastes. Pesticide Waste Class, Casmalia Resources, Casmalia, California. Report of ZIMPRO, Inc, Rothschild, Wisconsin. June 8, 1984.

Canney, P. J. 1984b. Commercial Demonstration of Wet Air Oxidation of Hazardous Wastes. Solvent Still Bottoms Waste Class, Casmalia Resources, Casmalia, CA. Report of ZIMPRO, Inc., Rothschild, Wisconsin. June 15, 1984.

Dietrich, M. J. 1983a. Commercial Demonstration of Wet Air Oxidation of Hazardous Waste Phenolic and Organic Sulfur Waste Classes. Casmalia Resources, Casmalia, California. Interim Report of ZIMPRO, Inc. June 27, 1983.

Dietrich, M. J. 1983b. Commercial Demonstration of Wet Air Oxidation of Hazardous Wastes. General Organic Waste Class, Casmalia Resources, Casmalia, California. Report of ZIMPRO, Inc. October 17, 1983.

Dietrich, M. J. 1983c. Commercial Demonstration of Wet Air Oxidation of Hazardous Wastes. Cyanide Waste Class, Casmalia Resources, Casmalia, California. Report of ZIMPRO, Inc. October 21, 1983.

I. TECHNOLOGY: Catalyzed Wet Oxidation

DEVELOPER: IT Corporation

II. PROCESS DESCRIPTION

Catalyzed wet oxidation (CWO) is based upon a potential process which uses nitrate and bromide ions in an acidic solution to catalyze the oxidation of organics by oxygen. There are other catalysts, such as copper ion, which have been used to improve the performance of conventional wet oxidation processes.

In simplest form, the reactor, a continuously stirred tank reactor (CSTR) contains the catalyst solution. Air and the waste are continuously pumped into the reactor, and the organics are oxidized with the heat of reaction driving off water. The only materials to leave the reactor are CO_2, N_2, water vapor, any volatile organics and inorganic solids formed. Water is condensed and returned to the reactor, if necessary, as are condensable organics. Any inorganic salts or acids which may be formed have to be removed by treatment of a closed loop stream of catalyst solution. Such treatment is individually designed utilizing conventional technologies, such as filtration or distillation. The vent gases from the reactor are low in volume and may, if necessary, be treated by conventional techniques, such as absorption, adsorption, or scrubbing, The most important features of this process concept are that nonvolatile organics remain in the reactor until destroyed, and that there is no aqueous bottoms product.

III. ADVANTAGES

In conventional wet oxidation processes, organics in water at levels not exceeding 1-3 percent are oxidized at temperatures of 200°-300°C (400°-575°F) and at pressures of 70-140 atm. The addition of catalysts that promote oxygen transfer and facilitate the creation of radicals that enhance oxidation has the effect of lowering the necessary temperatures of oxidation and/or increasing the rate of reaction and the degree of destruction (oxidation). The CWO process can also oxidize such substances as PCBs and

TCDD, substances generally not oxidized using conventional wet oxidation, although extreme conditions of time, temperature, and catalyst concentration are required.

IV. OPERATING CONDITIONS

Form of Feed Materials:	Aqueous streams with 1 to 5 percent organics, or pumpable liquid organic residues.	
Temperature Range:	325°-530°F (165°-275°C)	
Residence Time Range:		
Gas Phase:	<0.5 to 200 minutes	for back mix single reactor system
Solid (or liquid) Phase:	30-120 minutes	
Energy Type and Requirements:	Electrical power, primarily for air compression; steam for startup and temperature maintenance, unless organic concentration provides sufficient combustion heat.	

V. PERFORMANCE TEST RESULTS

Destruction of a wide variety of toxic and hazardous organic chemicals has been achieved by catalyzed wet oxidation employing a unique patented catalyst system. Complete oxidation of the organics is achieved by this IT Enviroscience process at lower temperatures and pressures than conventional uncatalyzed wet oxidation processes. The process is effective for destruction of both organically contaminated aqueous waste and organic residues. The catalyst system is comprised of an aqueous solution of nitrate and bromide anions. Bench-scale batch oxidations in the temperature range of 165-250°C (330-480°F), with pressures in the range of 175-900 psia, have shown the destruction of compounds such as 2,4-D, nitrophenols, chlorophenols, PCBs, dioxins, trichlorobenzenes, and Atrazine (Miller et al., 1980).

VI. COST ESTIMATES

Capital:	$0.75-1.5 million DFC for a system to treat either 0.3-3 million lb/yr of organic residue (liquid) or 5-30 gpm of dilute (<5 percent) aqueous.

Operating: $200-500 million/yr for same cases.

Total Per Unit of Feed: $0.10-2.00/lb organic or for dilute aqueous.
$0.01-0.10/gal.
$200-$4000/ton of organic material.
$2.50-$2.25/ton of solution.

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

IT has not pursued development of the bromide-nitrate catalyzed WAO process technology beyond bench-scale. ZIMPRO has many full-scale WAO systems operating, some of which presumably use some catalysts. The market for CWO is limited and should fit the gap between incineration and various chemical/-physical and biological wastewater treatment systems. Complex moderate strength (1-5 percent) aqueous wastes having high toxicity and organics with relatively high vapor pressures would be well suited for potential application, particularly if effluent could be discharged to a municipal or industrial secondary treatment plant, which eliminates the difficulty of achieving very high treatment efficiencies (>98 percent).

VIII. FOR MORE INFORMATION

IT Enviroscience, Inc.
9041 Executive Park Drive
Knoxville, Tennessee 37923
(615) 690-3211

IX. REFERENCES

Miller, R. A., J. D. Johnson, R. W. Helsel, and D. M. Pitts. 1980. Destruction of Toxic Chemicals by Catalyzed Wet Oxidation. Presented at the Purdue Industrial Waste Conference, West Lafayette, Indiana. Report of IT Enviroscience, Inc., Knoxville, Tennessee. May 1980.

I. TECHNOLOGY: Supercritical Fluid Oxidation

DEVELOPER: MODAR, Inc.

II. PROCESS DESCRIPTION AND SCHEMATIC

Supercritical fluid oxidation is basically a high temperature, high pressure wet oxidation. Above the critical temperature, 374°C (705°F) and pressure (218 atm) of water, organic materials and gases are completely miscible with water. In supercritical water oxidation, organics, air, and water are brought together in a mixture at 250 atm and temperatures above 400°C (750°F). Organic oxidation is initiated spontaneously at these conditions. The heat of combustion is released within the fluid, and it results in a rise in temperature to 600°-650°C (1100°-1200°F). Under these conditions, organics are destroyed rapidly with efficiencies in excess of 99.999 percent. Heteroatoms are oxidized to acids which can be precipitated out as salts by addition of bases to the feed.

A schematic flowsheet for a MODAR process for treating an aqueous waste containing 10 wt% organic is given in Figure 4. This process consists of the following steps.

1. The waste, as either an aqueous solution or a slurry, is pressurized and delivered to the oxidizer inlet. It is heated to supercritical conditions by direct mixing with recycled reactor effluent.

2. Oxygen is supplied in the form of compressed air, which is used as the motive fluid in an eductor to provide recycle of a portion of the reactor effluent. This inlet mixture is then a homogeneous phase of air, organics, and supercritical water.

3. The organics are oxidized in a controlled but rapid reaction. The short residence times that are required allow adiabatic operation of the oxidizer. The heat released by combustion of readily oxidized components is sufficient to raise the fluid phase to temperatures at which all organics are oxidized rapidly.

4. The effluent from the oxidizer is fed to a cyclone. The solubility of inorganics in SCW is extremely low at the reactor effluent temperatures. Inorganic salts that are originally present in the feed, or which form in the combustion reactions, precipitate out of the fluid phase in the oxidizer and are separated here.

5. The fluid effluent of the solid separator consists of superheated SCW, N_2, and CO_2. A portion of this is recycled through the eductor to provide supercritical conditions at the oxidizer inlet.

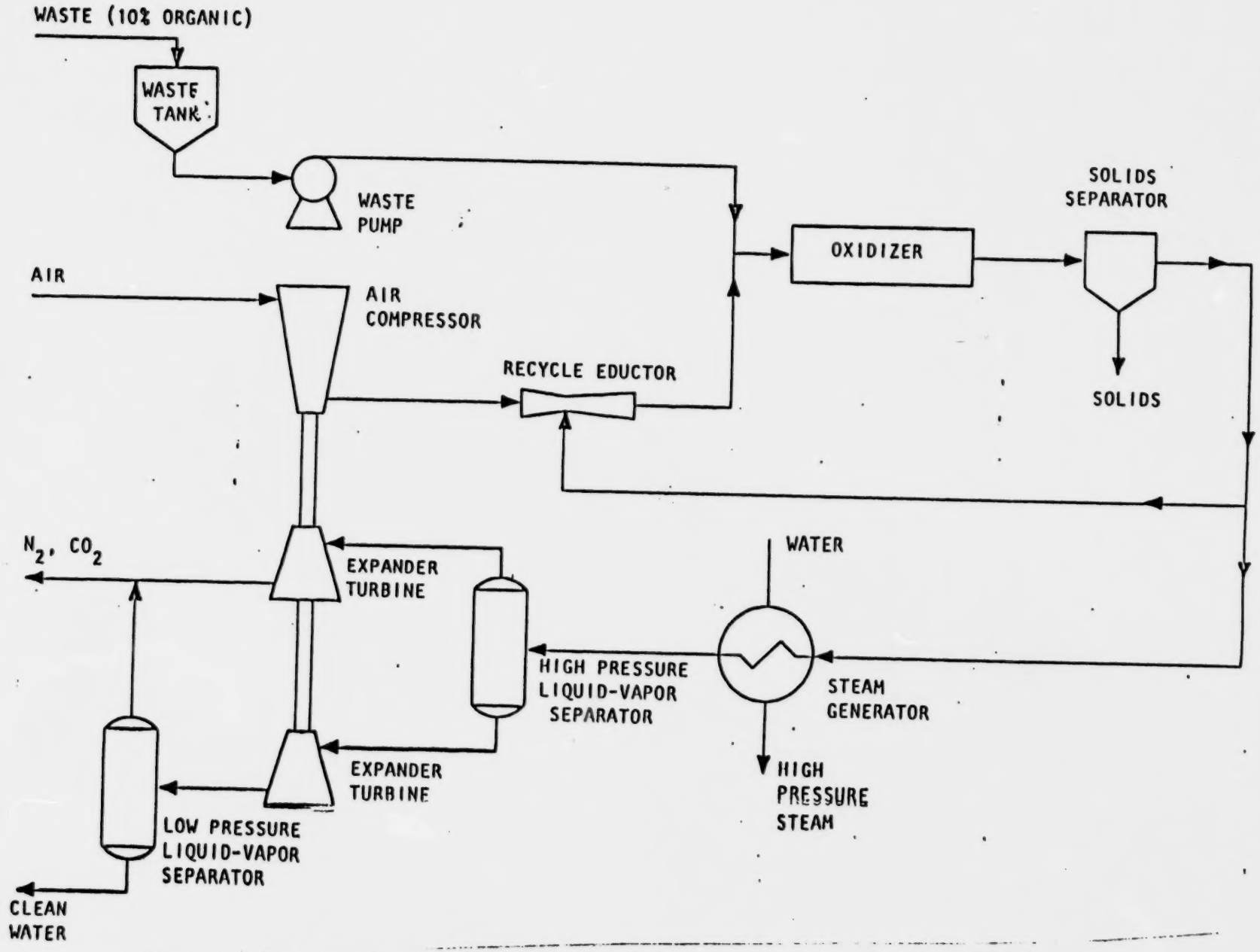


Figure 4. **Process schematic for oxidation of an aqueous waste with a heating value of 1750 Btu/lb.**

6. The remainder of the effluent is available as a high-temperature, high-pressure fluid for energy recovery. This stream is cooled to a subcritical temperature in a heat exchanger which serves to generate low-pressure or high-pressure steam.

7. Now at a subcritical temperature, the mixture has formed two phases and enters a high-pressure liquid-vapor separator. Almost all of the N_2 and most of the CO_2 leaves with the gas stream. The liquid consists of water with an appreciable amount of dissolved CO_2.

8. The gas and liquid streams can then be expanded through turbines to extract the available energy as power. A portion of the power is used for compression of the inlet air.

9. The effluent from the liquid turbine enters a low-pressure separator. The vapor stream is primarily CO_2 which is vented with the gas turbine effluent. The liquid stream is clean water.

III. ADVANTAGES

The developer states that the MODAR process for supercritical water oxidation of organics is an improvement in--

- o enhanced solubility of oxygen and air in water, which eliminates two-phase flow;
- o rapid oxidation of organics, which approaches adiabatic conditions as well as high outlet temperatures, and very short residence times;
- o complete oxidation of organics, which eliminates the need for auxiliary offgas processing;
- o removal of inorganic constituents, which precipitate out of the reactor effluent at temperatures above 450°C (840°F); and
- o recovery of the heat of combustion in the form of supercritical water, which can be a source of high-temperature process heat or used to generate power in conventional supercritical turbines.

IV. OPERATING CONDITIONS

Form of Feed Materials:	Aqueous slurry or solution of organics.
Temperature Range:	400°-650°C (750°-1200°F)
Pressure Range:	220-300 atm
Residence Time Range:	5 to 10 seconds
Energy Type and Requirements:	Thermal, to reaction conditions, with provisions for useful recovery of latent heat of combustion.

V. PERFORMANCE TEST RESULTS

The destruction efficiency (defined herein as the conversion of organic materials in the feed to final oxidation of products of CO_2, H_2O, and acids or oxyacids of heteroatoms and metals) is a function of reactor temperature and residence time. The developer has found that a reactor effluent temperature in the range of 600° to 650°C (1110° to 1200°F) and residence time 5 sec are sufficient for a destruction efficiency of more than 99.99 percent. Higher temperatures could be used to reduce the residence time. However, at 5 sec residence time, the reactor cost is a small fraction of total capital cost, and, therefore, there is not much incentive to try to reduce reactor volume by operating above 650°C (1200°F) (Modell, 1984).

VI. COST ESTIMATES

Cost estimates as provided by MODAR, Inc., are included as Table 3.

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

A 50-gallon per day pilot plant is under development to provide a verification of the laboratory-scale results.

VIII. FOR MORE INFORMATION

MODAR, inc.
14 Tech Circle
Natick, Massachusetts 01760
(617) 655-7741

IX. REFERENCES

Modell, Michael, and T. B. Thomason. 1984. Supercritical Water Destruction of Dilute Aqueous Wastes. Presented at the 2nd International Symposium on Operating European Centralized Hazardous (Chemical) Waste Management Facilities, Odense, Denmark. Report of Modar, Inc., Natick, Massachusetts. September 1984.

TABLE 3. DISPOSAL COSTS FOR DILUTE AQUEOUS WASTES

Waste Capacity		Heat Release Rate		Processing Cost**	
gal/day*	ton/day*	Btu/h	J/S	$/gal*	$/ton
10	0.04	6,000	2,000	(Bench scale)	---
500	2	300,000	90,000	(Demo scale)	500
2,500	10	1,500,000	400,000	0.80	200
5,000	20	3,000,000	900,000	0.50	120
12,500	50	7,300,000	2,200,000	0.25	60
25,000	100	14,600,000	4,300,000	0.15	40

*Based on an aqueous waste with 1,750 Btu/lb or 4.1 kJ/g heating value, which is approximately 10 wt% of benzene-equivalent.
**Tolling cost to waste generator.

I. TECHNOLOGY: High-Temperature Wet Oxidation

DEVELOPER: Methods Engineering, Inc.

II. PROCESS DESCRIPTION AND SCHEMATIC

The apparatus consists of a long, vertical, underground tubular reactor. As shown in Figure 5, two tubes are arranged concentrically allowing the waste to be pumped down the inner tube and the treated waste to flow up the annulus. An electrode is positioned near the bottom of the reactor as shown and used to furnish initial resistance heating. After the temperature is high enough (about 230°C, 450°F), oxygen and organic waste is introduced so that the exothermic reaction can sustain and increase the temperature to above 374°C, 705°F. The electrode then functions to provide cathodic protection to the tubing. The depth of the reactor should be such that enough hydrostatic head is available to permit operation above the critical point of water. If the depth is sufficient, the pump will only need to overcome friction losses.

III. ADVANTAGES

The developer states the following:

1. The pressures are contained by standard tubing such as used in the oil field.
2. The heat exchange is an integral part of the design.
3. Mild steel can be used as the material of construction.
4. A wide range of concentrations and flows can be accommodated.

IV. OPERATING CONDITIONS

Form of Feed Materials:	Toxic wastes in the liquid, solid, or vapor phase can be accommodated.
Temperature Range:	230°-425°C (450°-800°F)
Pressure Range:	220 to 300 atm
Residence Time Range:	Seconds (in the supercritical zone)

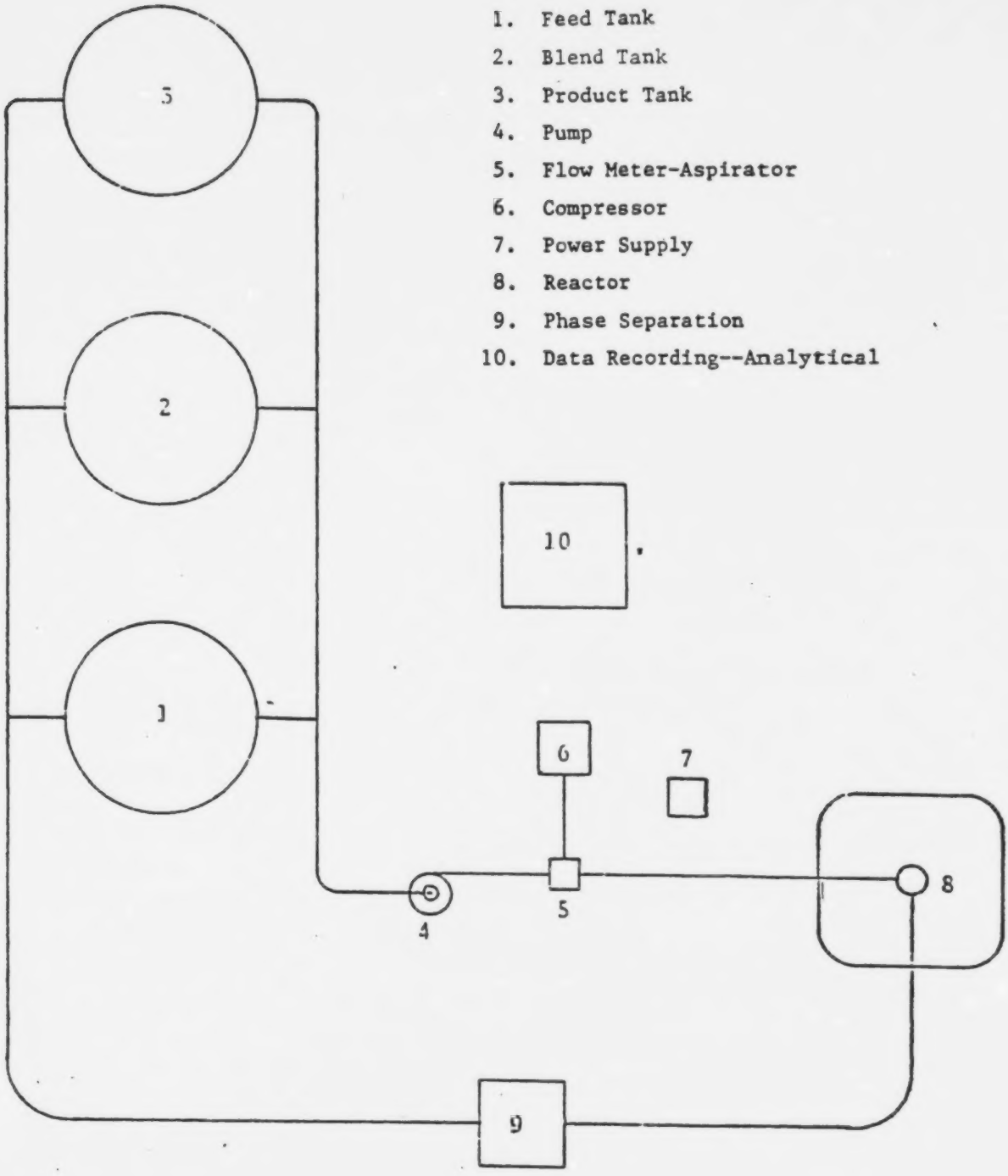


Figure 5. Schematic of reactor and supporting systems.

Energy Types and Requirements: Electric drive for the pump and the compressor. D.C. power supply for the electrode.

V. PERFORMANCE TEST RESULTS

None yet.

VI. COST ESTIMATES

The developer provides the following:

Capital Estimate

Well 10,000' and Tubing	$ 1,000,000
Tankage 3 x 10,000 gal	30,000
Pumps 1,000 gpm	5,000
Compressor 200 cfm 2,000 psig	5,000
Power Supply 20 kW	5,000
Instrumentation/Controls	50,000
Control Lab/Control House	50,000
Land/Acre	20,000
Total	$ 1,165,000

Operating Costs/Year Estimate

Operators - two/shift	$ 340,000
Power 500 hp 5¢/kWh	160,000
Depreciation 10% cap.	116,000
Royalty	100,000
Total	$ 716,000

Capacity 1,000 gpm at 0.1% organics
1000 gal/min x 60 min/hr x 8000 h/yr = 480,000,000 gal/yr.

When operating above 0.2 percent, organics would require cooling tower at the surface. Heat release is about 2,000,000 Btu/h for 100 ppm organics. At 0.1 percent organic, heat release is about 20,000,000 Btu/h. About 2,000,000 Btu/h would be lost to the earth, so at 100 ppm organic, the temperature of the water out would be the same as water in. At 0.1 percent organics, the temperature differential at the surface would be 40°F.

Total Cost: $50.35/ton.

$716,000/yr ÷ 480,000,000 gal/yr = $0.0015/gal.

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

Patent pending. Seeking funding to install system and collect data.

VIII. DEVELOPER INFORMATION

Methods Engineering is a small service engineering and development company located in Alvin, Texas.

Areas of expertise: Liquid/solid separation, petrochemical and refinery services, environmental specialty services.

Methods Engineering, Inc.
P. O. Box 282
Angleton, Texas 77515
(713) 331-7268

5.0 CHEMICAL TRANSFORMATION

Chemical Transformation--processes that transform the waste streams into other less toxic substances primarily through chemical reactions. These processes are important in that they are examples of technology to encourage resource recovery rather than destruction of wastes. As treatment processes become more the norm than landfills or even than incineration, chemical transformation processes will occupy a much larger segment of the waste management picture. This is especially true for those chemical processes that produce useful materials. Currently, these processes have difficulty competing with conventional disposal methods. However, as disposal costs rise, chemical processes such as the ones discussed in this report will become increasingly attractive.

The following chemical transformation processes are included:

Aqueous Phase Alkaline Destruction of Halogenated Organic Wastes--Battelle Northwest

Catalytic Dehalogenation of Hazardous Waste--GARD Division, Chamberlain Manufacturing Co.

I. TECHNOLOGY: Aqueous Phase Alkaline Destruction of Halogenated Organic Wastes

DEVELOPER: Battelle-Northwest

II. PROCESS DESCRIPTION

Organic matter is digested at 250°-400°C (480°-750°F) with mild alkali under pressure, and in the absence of oxygen. The result is the conversion of organic solids into an oil, which under some circumstances can have a heating value of up to 90 percent that of diesel oil. The product oil is easy to separate from the wastewater, and is generated in up to 70 percent of theoretical energy yield.

III. ADVANTAGES

1. Energy efficiency, with recovery of up to 70 percent of theoretical energy yield in the form of an oil resembling diesel oil.
2. Reducing conditions minimize oxidative formation of dioxins.
3. Based in standard industrial technology for production of phenol by reaction of chlorobenzene with alkali.

IV. OPERATING CONDITIONS

Form of Feed Materials: Halogenated liquids and granular solids, including such materials in attendant organic polymers (cellulose and lignin from paper and rags, biomass, etc.)

Temperature Range: 250°-400°C (480°-750°F)

Pressure Range: 500-3000 psi

Residence Time Range: 0.5 to 5 hours

Energy Type and Requirements: Thermal, sensible heat for reacting materials.

V. LABORATORY TEST RESULTS (Preliminary)

The results of preliminary experiments on several chlorinated materials are summarized in Table 4. Lindane and chloroform were almost totally destroyed, and a 2,4,5-T analog was partially degraded, demonstrating the ability of alkali under these conditions to remove both aromatic and aliphatic chlorine atoms from organic molecules. The identities of the starting material was confirmed by gas-chromatography/mass spectrometry. Products were not specifically identified because of time limitations, apart from a comparison of spectra with dioxins from the chlorinated phenolic starting material. None were observed.

VI. COST ESTIMATES

Not available at this time

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

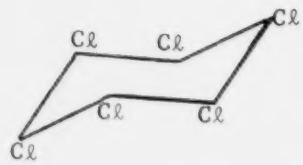
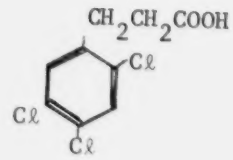
Although the process is a straightforward extension of industrial technology for phenol production and of newer technology for fuel production by direct liquefaction, its application to hazardous waste destruction is still at the laboratory research scale. Research needs are the following:

- Investigate the types of toxic chemicals vulnerable to this type of chemical attack.
- Study the range of conditions necessary for optimum destruction of different classes of toxic chemicals.
- Identify the products, which should be identified to determine that they are less harmful than the starting materials.

VIII. FOR MORE INFORMATION

Battelle
Pacific Northwest Laboratories
P. O. Box 999
Richland, Washington 99352
(509) 375-2927

TABLE 4. LIQUEFACTION OF MODEL CHLORINATED ORGANIC COMPOUNDS

Compound	Structure	Concentration*	Temperature°C	Time	Destruction
Chloroform	$CHCl_3$	0.8%	290	1 h	Total
Lindane (25% mixed isomers)		0.8%	290	1 h	99%
2,4,5-Trichlorophenyl propionic acid		0.8%	290	1 h	<10%
		0.8%	350	1 h	>20%

*120 mL water.
1.91 g Na_2CO_3 (0.30N).
4 g 0.25% lindane or 1.0 g chloroform or 1.0 g of 2,4,5-T analog.

I. TECHNOLOGY: Catalytic Dehalogenation of Hazardous Waste

DEVELOPER: GARD Division, Chamberlain Manufacturing Corporation

II. PROCESS DESCRIPTION AND SCHEMATIC

Two processes are suggested; one for liquids containing low concentrations of halogenated compounds (for example, silvex), and another for liquids present as pure halogenated compounds or their solutions in high concentrations (for example, ethylenedibromide, EDB).

1. First Process, Catalytic Hydrodehalogenation

A typical hydrodehalogenation reaction may be expressed as:

$$R\text{-}(X)_n + nH_2 \xrightarrow[\Delta]{\text{catalyst}} R\text{-}(H)_n + nHX$$

where R indicates an aliphatic or aromatic hydrocarbon radical.

Each halogen atom of the halogenated compound is replaced by a hydrogen atom, resulting in a fully hydrogenated aliphatic or aromatic hydrocarbon. Typically, the solvent is not affected by the catalytic dehalogenation process. Thus, the final product will consist of a mixture of the original solvent and the dehalogenated (now hydrogenated) compound which has economic value.

A schematic of the process is presented in Figure 6. From storage, halogenated hazardous material is pumped through a preheater to the hydrodehalogenation reactor where, in the presence of a suitable catalyst, it reacts with hydrogen. Oil and other hydrocarbons which may be present as solvents or impurities will remain essentially unchanged because of the relatively mild processing conditions (3-10 atm, 150°-200°C (300-400°F). The excess hydrogen is recycled; in addition, the product recycle is built into the system to safeguard against incomplete reaction due to upset conditions or cases where a single pass would not achieve the desired degree of dehalogenation.

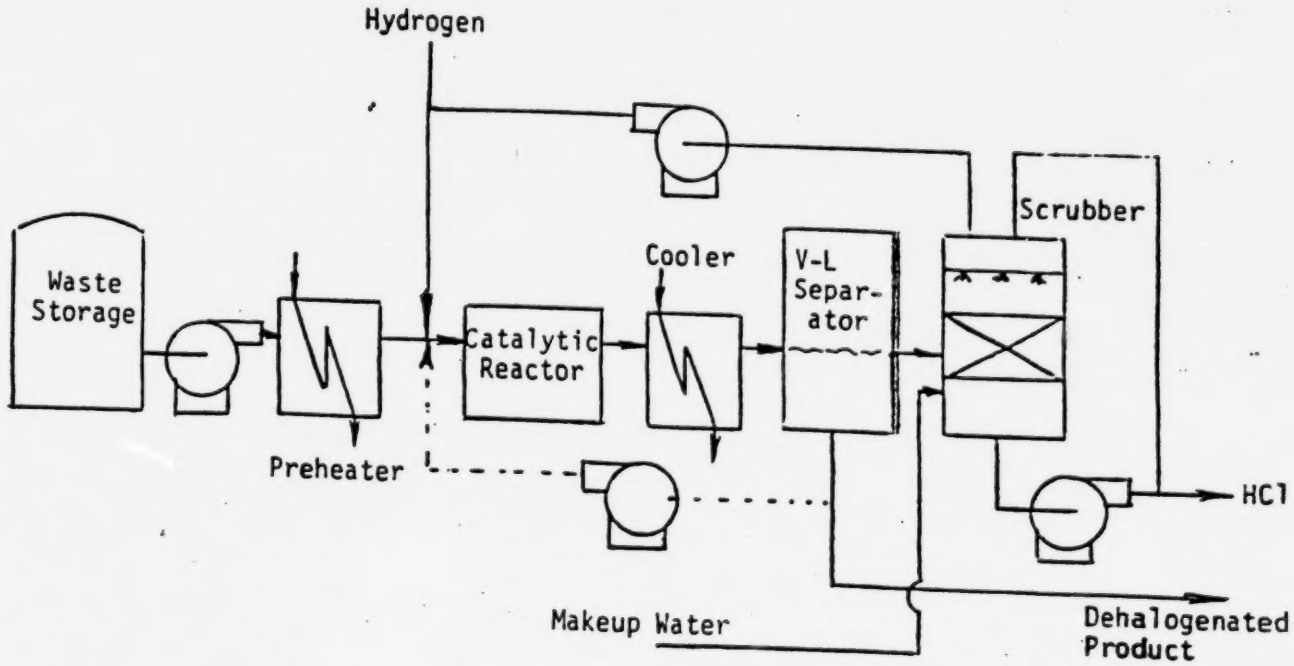


Figure 6. System for hydrodehalogenation.

Reaction product leaving the reactor is cooled; then, following a vapor/liquid separation stage, the dehalogenated hydrocarbon product and halogen acid collected in a scrubber are transferred to storage.

2. Second Process, Catalytic Debromination of EDB

Ethylenedibromide (EDB) is usually used directly instead of dissolved in a solvent; therefore, there is no solvent to recover. Debromination of EDB is possible either by catalytic hydrodebromination described above or by catalytic oxidation according to the following reaction:

$$BrH_2C - CH_2Br + 3O_2 \xrightarrow[\Delta]{\text{catalyst}} Br_2 + 2CO_2 + 2H_2O$$

In this process, ethylene is oxidized to CO_2 and provides the energy for maintaining the catalyst temperature 425°-535°C (800°-1000°F) required for a complete removal of EDB. In addition, bromine can be easily condensed and recovered, while the hydrodebromination results in ethylene and HBr that are more difficult to capture.

Catalysts have been developed (patent application is in preparation) and tested in a laboratory bench-scale setup shown in Figure 7. EDB was vaporized by bubbling a stream of air through it, then passed through the catalyst at atmospheric pressure; bromine produced by the reaction was condensed in a water-cooled condenser. At catalyst temperatures of 425°-535°C (800°-1000°F), an essentially complete conversion of EDB to BR_2 and CO_2 was obtained.

III. ADVANTAGES

This process treats halogenated compounds by replacing the halogen atoms with a hydrogen atom. Typically, these compounds are found as liquid solvents. This process retains the economic value of such materials while rendering the halogenated compounds in them harmless.

Relatively mild operating conditions result in uncomplicated equipment. Data suggest a full-scale system would be small enough for moving to the cleanup sites.

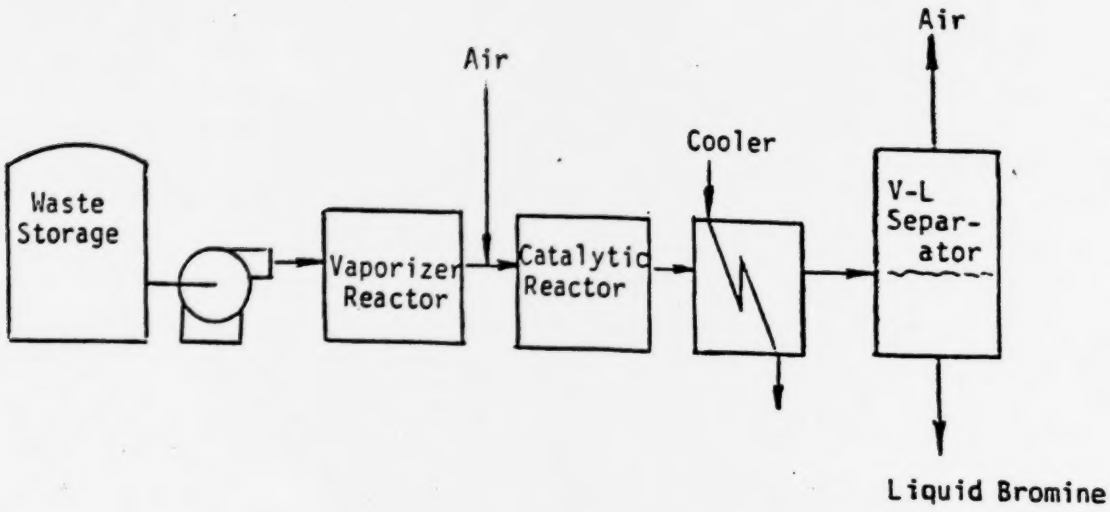


Figure 7. System for catalytic treatment of E..B.

IV. OPERATING CONDITIONS

Form of Feed Materials: Liquid halogenated solvents
Supplementary hydrogen

Temperature Range: 150°-200°C (300°-400°F)

Pressure Range: 3-10 atm

Residence Time Range: 10-20 minutes (liquid)

Liquid Phase: Hourly Space Velocity (LHSP): 3-6 $V_e V_c^{-1} h^{-1}$

Energy Type and Requirements: Sensible heat to 150°-200°C (300°-400°F); latent heat of reaction.

Electrical to pump feed to desired pressure.

Feed Streams: Hydrogen, oils, solvents, halogenated wastes

Product Streams: Hydrogen for recycle, oils, solvents, dehalogenated wastes

Possible Emissions and Effluents: Unreacted feed material, catalyst, halogen acids.

V. PERFORMANCE TEST RESULTS

Gard, Inc., has evaluated the dehalogenation activities of various precious metal catalysts (platinum, palladium, rhodium) for silvex formulations and PCB solutions in solvents and oils. Using an unoptimized bench-scale reactor containing a promoted platinum-based catalyst (a patent application is being prepared), dechlorination exceeding 99.9 percent of silvex formulations initially containing 9.4 percent of chlorinated phenoxy esters and 93.5 percent removal of PCB from a 2,080 ppm solution in oil were achieved.

VI. COST ESTIMATES

Capital: $100,000 for a system treating wastes at a rate of 50/gal/min.

Operating: $300.00/hour, or $32.00/long ton (1000 kg) of liquid waste.

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

Both catalytic dehalogenation processes described above have been tested in laboratory bench-scale reactors and their feasibility established. The next step would be process and catalyst optimization and collection of data for a design of field-size systems. Both systems would be relatively small, suitable for moving to the cleanup sites. The hydrodehalogenation system is essentially the same as used for hydrogenation in the oil industry; thus, components and/or entire system are available from commercial sources.

VIII. DEVELOPER INFORMATION

GARD is a research and development organization which has provided services to government and industry since 1953 when it was first organized as the Mechanics Research Division (MRD) of American Machine and Foundry (AMF) Company. In 1962 it was purchased by GATX Corporation and became General American Research Division, later known as GARD. Subsequently in April 1984, GARD was purchased by Chamberlain National and became the GARD Division of Chamberlain Manufacturing Corporation.

Chamberlain National
GARD Division
7501 North Natchez Avenue
Niles, Illinois 60648
(312) 647-9000

6.0 MOLTEN GLASS

Molten Glass--processes that use a pool of molten glass as the heat transfer mechanism to destroy organics. The attractiveness of molten glass is based upon the extremely good quality of the residue from the process, i.e., essentially nonleachable glass. The combustion conditions for organics appear to be at least as good as those present in hazardous waste incinerators, and the inorganic residue and ash is incorporated into the glass. Introduction of this type of technology into the waste management industry, especially for highly toxic organic streams containing toxic metals, could prove very attractive if it can be shown through extraction tests that the residue is nonleachable and may be delistable as a hazardous waste.

The following processes are included:

Joule Heated Glass Melter--Battelle Northwest
Electromelt Pyro-Converter--Penberthy Electromelt International

I. TECHNOLOGY: Joule-Heated Glass Melter

DEVELOPER: Battelle-Northwest

II. PROCESS DESCRIPTION

In the glass industry, joule heating refers to utilizing the material being heated as the resistance element in an electrical circuit, thus avoiding the necessity of transferring heat from a metallic resistance element.

It is thought that the glass melter would be highly adaptable to the destruction and fixation of industrial contaminated soils. The process would accept contaminated soils directly, eliminating any pretreatment steps. In a single step, the organic constituents would be destroyed and/or combusted at temperatures of 1200°C (2200°F), and the inorganic constituents and soil would react with a relatively small amount of glass formers to create a glass matrix. The gaseous effluents, resulting from the destruction organic contaminants, are composed of normal products of combustion (i.e., H_2O, CO_2, and sometimes HCl depending on the type of organic). An offgas treatment system similar to those for conventional waste incinerators would treat the effluents to environmentally acceptable levels. Molten glass in the melter is continuously drained into an inexpensive receiving canister, cooled to ambient, and dispersed in an appropriate shallow land burial site.

III. ADVANTAGES

The developer states the following:

The glass, incorporating the inorganic contaminants such as heavy metals, is in itself a long-term disposal medium exhibiting leaching rate properties similar to Pyrex or granite. It is the proposed waste form for high-level nuclear wastes to be disposed for geologic periods in underground repositories. It is expected to meet the most stringent proposed disposal criteria for industrial wastes. The specially formulated glass compositions are chemically inert, contain no water and do not hydrate, are high strength and fracture resistance, and have extremely low leach rates.

Complete combustion can be achieved with a special feeding technique; hence no secondary treatment is necessary.

High retention of heavy metals is achieved.

IV. OPERATING CONDITIONS

Form of Feed Materials: Organically contaminated soils and other granular mineral matter.

Temperature Range: To 1200°C (2200°F)

Residence Time Range:

Gas Phase

Solid (or liquid) Phase

Energy Type and Requirements: Electrical, supplying latent heat to elevated temperatures and sensible heat for melting.

V. PERFORMANCE TEST RESULTS

The process retains greater than 95 percent of nonvolatile heavy metal elements at 1200°C (2200°F) and greater than 80 percent of semivolatiles (based on retention figures of Sr and CS, respectively). The high efficiency of combustion and retention of heavy metal contaminants is achieved by intermixing the feedstock and their combustion gases with the molten glass. This achieves a scrubbing action, keeping particulate carryover to a minimum (i.e., 0.45 percent of feedstock). Entrained particulates and contaminants removed by the offgas system could be recycled to the melter if desirable to eliminate secondary waste streams.

VI. COST ESTIMATES

Not available

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

With the special feeding technique employed in the melter, a more rapid processing rate is expected with the joule-heated glass melter than with conventional melters. The melter could be scaled to meet the requirements of a waste treatment operation designed to process numerous tons per day. The melter would be expected to have a 10-year lifetime, requiring replacement of the ceramic linings and some of the other high-temperature components once every 2 to 3 years. The melter technology has the potential of being a highly adaptable and economical tool for contaminated soil treatment.

VIII. FOR MORE INFORMATION

Battelle
Pacific Northwest Laboratories
P. O. Box 999
Richland, Washington 99352
(509) 375-2927

I. TECHNOLOGY: Electromelt Pyro-converter

DEVELOPER: Penberthy Electromelt International

II. PROCESS DESCRIPTION AND SCHEMATIC

Waste, both combustible and noncombustible, is charged onto a pool of molten glass in an electric furnace. The waste is burned to ashes (or dried to solids) which are immediately melted into the glass, all in the same chamber. Excess glass is drained off from time to time into canisters for ultimate disposal. The glass compositions used are very stable.

Referring to Figure 8, solid wastes, which can be in fiberboard boxes or loose, are pushed through the door opening into the glass furnace, which is heated electrically by immersed electrodes. Liquid and slurry wastes are introduced at a controlled rate through a pipe. If the liquid base is water, the water boils to steam progressively, leaving solids behind. If the liquid is oil, toluene, or other organics, the liquid burns to CO_2, H_2O, and HCl (if a chlorinated compound). Dirt and noncombustible content drop onto the glass and melt in. The gases go up through the filter to the spray chambers where the HCl is converted to common salt (NaCl).

The entire molten glass pool is kept above 2300°F (1260°C), which is well above the ignition temperature for combustible materials. These materials burn with admitted air in the first half of the chamber, while the second half of the same chamber "polishes" the process to insure complete combustion. Ashes and any noncombustible materials that drop onto the surface of the glass are melted into the glass. Wet, spent, ion-exchange resins first lose the water and then burn as above. Radioactive metal oxides drop and are melted into the glass. Complementary raw materials, if needed, are charged into the furnace via a screw charger.

The flue gases pass through a set of ceramic fiber filters which catch substantially all of the particulate. When each filter in turn is loaded, it is pushed into the furnace where it dissolves, capturing the dust into the glass. The flue gases then go through a gas-to-water heat exchanger and then

Penberthy PYRO-CONVERTER™

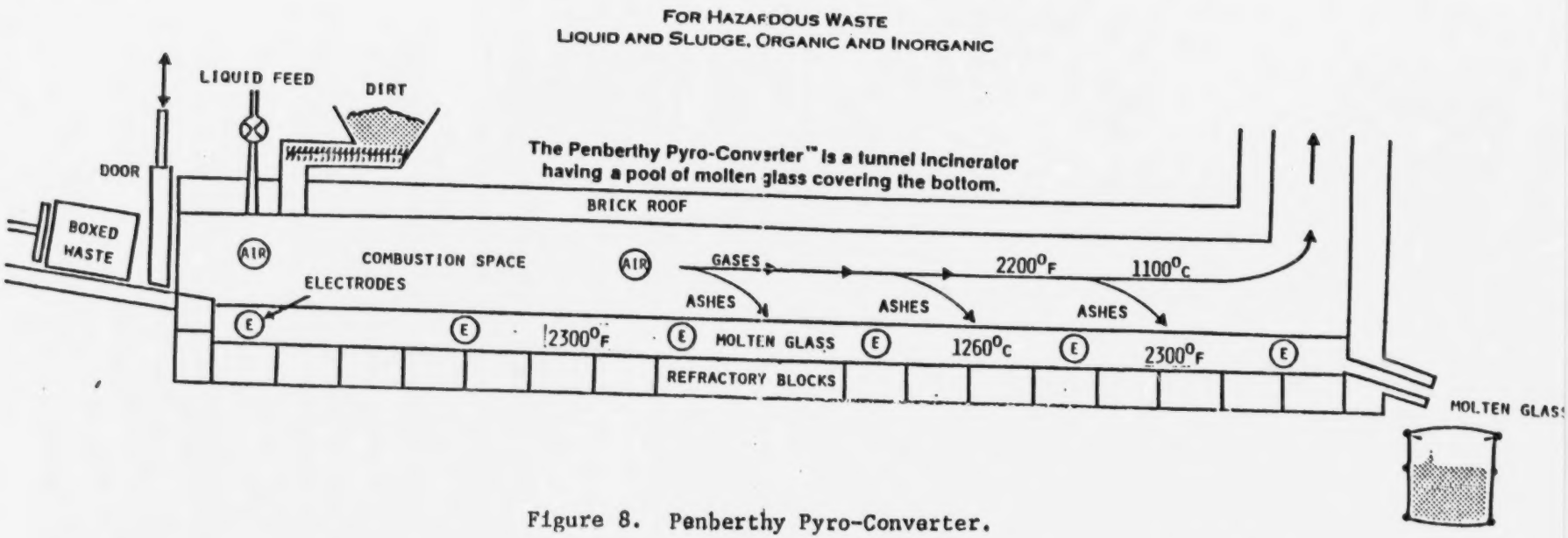


Figure 8. Penberthy Pyro-Converter.

to two water spray chambers. The first spray is held slightly alkaline to capture acidic gases. The water in the second chamber is fairly pure to prevent loaded water from passing onward into the rest of the system. The demist chamber takes out practically all of the droplets. The gases are then reheated above the dewpoint. The gases then pass through charcoal and HEPA filters before going to the blower and out of the vent stack.

Filter sludge from the spray chambers and the charcoal and HEPA filters are disposed of in the furnace. The charcoal burns to carbon dioxide and the dust and sludges are melted into the glass. HEPA filters (no metal parts) melt into the glass pool, capturing their contained dust.

The glass is tapped off from time to time as necessary into canisters. After cooling, the canisters are ready for final disposal.

The entire system is maintained under negative pressure by means of the exhaust blower. Combustion air is admitted to the furnace through ports which control oxygen as desired, usually 4 percent minimum for completeness of combustion.

III. ADVANTAGES

1. Significant volume reduction.

2. The product being shipped is a good glass, fully stable under all transportation conditions. Glass compositions are also fully stable under all reasonable storage and final disposal conditions.

3. The equipment is small enough to be installed on the site where the waste is being generated. No loose or liquid waste needs to be transported.

4. The offgas volume is held to the minimum because no added oil or gas is required.

5. The equipment and flow sheet are relatively simple, built on basic technology that has been applied in heavy industry for 30 years.

IV. OPERATING CONDITIONS

Form of Feed Materials:

The developer states the following:

Model 8172 Pyro-Converter is extremely versatile and will handle a large variety of wet or dry waste products, including:

Exothermic Waste	Volume Reduction
Rubber, plastic	practically no ash The ratio of VR is very high
Rags, wood, paper (compacted or loose)	30 to 1
Ion-X resins, detergents	practically no ash
Charcoal filters	30 to 1
Urea-formaldehyde, wet or dry	practically no ash
Bitumen, asphalt	100 to 1
Arsenicals (organic)	40 to 1
PCBs, pesticides, herbicides	10 to 1
Toluene, organics in general	practically no ash
Epoxy	practically no ash
Oil	practically no ash
Endothermic Waste	**Volume Reduction**
Boric acid (12% solution)	6 to 1
Contaminated Water	Depends on inorganic solids content
Electroplating solutions	Depends on inorganic solids content
Dirt, gravel, concrete, cement	1 to 1
Caustic soda (15% solution)	2 to 1

Oxides of iron, chromium, barium lead, cobalt, molybdenum, arsenic, copper, antimony, et al.	0.1 to 1
Filter and electropolishing sludges	0.1 to 1
Filter sand, HEPA filters (except metal parts)	0.1 to 1
Fission products, radioactive (dry or wet)	0.3 to 1
Animal carcasses	10 to 1
Glass	1 to 1
Vermiculite, diatomite	20 to 1

Waste Sulfates

Sodium sulfates in small amounts (up to 1% of the final glass being discharge) can be incorporated without attention. Larger amounts are a special case. Please inquire.

Temperature Range: 1250°C (2300°F)

Residence Time Range:

Gas Phase: 2 seconds, longer if desired

Solid (or liquid) Phase: Glass melting, two hours

Energy Type and Requirements: Electrical. For 2000 lb of tetrachlorobenzene per hour: 400 KWH/hr

V. PERFORMANCE TEST RESULTS

Tests in progress. One test showed 0.4 ppm Cl_2 in exhaust.

VI. COST ESTIMATES

Capital: For 2000 lb/hr tetrachlorobenzene or similar, about $1 million.

Operating: $100 per ton of feed.

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

The technology is offered commercially in sizes shown in Table 5. The Pyro-Converter is sold as chemical processing equipment, not as an incinerator. Smaller units are available for in-plant use. Larger units are available for use by disposal companies.

VIII. FOR MORE INFORMATION

Penberthy Electromelt International, Inc.
631 South 96th Street
Seattle, Washington 98108
(206) 762-4244

TABLE 5. PENBERTHY PYRO-CONVERTER® MODEL 8172
FOR RADIOACTIVE, TOXIC AND OTHER HAZARDOUS WASTES

Furnace Size Glass Bath Area	Furnace Outside Width x Length x Height	Box Size Maximum	Toluene, Oil Feed Rate	Spent Resins, Dry Basis	Wood, Cloth Paper	Glass
3 x 11 ft	6 x 14 x 6 ft	18 x 18 x 24"	50 liters/hr 125 lb/hr	-- --	400 lb/h	500 lb/h
3 x 22 ft*	6 x 25 x 8 ft	18 x 18 x 48"	130 liters/hr 250 lb/hr	250 lb/h	1000 lb/h	1000 lb/h
4.5 x 30 ft	7 x 33 x 8 ft	24 x 24 x 60"	500 lb/hr	500 lb/h	2000 lb/h	2000 lb/h
6 x 40 ft	9 x 43 x 10 ft	48 x 48 x 96"	1000 lb/hr	1000 lb/h	4000 lb/h	4000 lb/h

Larger sizes also available.

*An operating furnace of Model 8172, size 3 x 22 ft is available for demonstration in their Seattle facility.

7.0 FLUIDIZED BED INCINERATION

Fluidized-Bed Incineration--thermal processes using a very turbulent bed of inert granular material to improve the transfer of heat to the waste streams to be incinerated. Advantages of fluidized-bed incinerators include their relatively compact design, their relative simplicity of operation, and their ability for combining combustion with pollution control by trapping some gases in the bed. Although fluidized beds have been used for many years in various industries, their use in hazardous waste incineration is still at a demonstration level. It is generally agreed, however, that this approach to waste incineration offers significant potential for the future.

The following processes are included:

Multisolid Fluidized Bed--Battelle
Circulating Bed Waste Incineration--GA Technologies
Low Temperature Fluidized Bed--Waste Tech Services, Inc.

I. TECHNOLOGY: Multisolid Fluidized Bed

DEVELOPER: Battelle

II. PROCESS DESCRIPTION AND SCHEMATIC

The process is based on a circulating fluidized-bed concept. The key to the process is the use of a dense fluidized bed of large particles to which small particles of an entrained bed is superimposed. Interaction of the small and the large particles provides intensive mixing in the combustor, which simplifies fuel feeding and promotes efficient fuel combustion and limestone sulfation reactions. Another important feature of the process is decoupling of the combustor and the heat exchanger, which minimizes heat exchanger tube corrosion and erosion problems. Effective control of nitrogen oxides emissions is accomplished through a staged-combustion technique. A sketch of the combustor used in a heat recovery mode is shown in Figure 9.

III. ADVANTAGES

The developer states the following:

- Safe and economical disposal of solid, liquid, or gaseous wastes.
- Recovery of energy for steam generation, gas turbine, and process heaters.
- Control of sulfur oxides, nitrogen oxides, and other gaseous pollutants.
- Multifuel flexibility.
- Minimum feed preparation.
- Minimum risk in scale-up.

IV. OPERATING CONDITIONS

Form of Feed Materials:	Granular solids, sludges, slurries, liquids, gases.
Temperature Range:	540°-1100°C (1000°-2000°F) and up depending on ash fusion temperature.

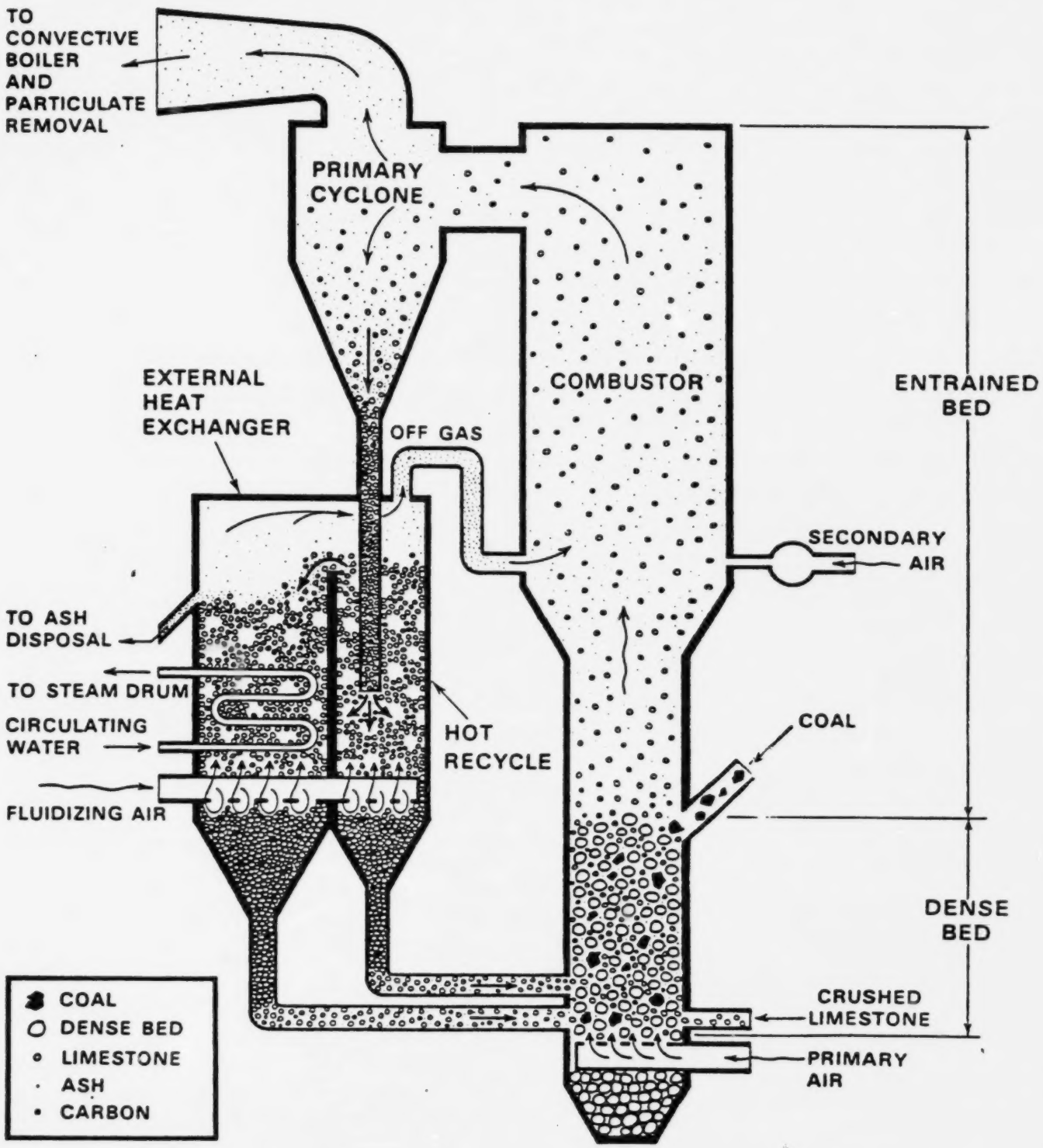


FIGURE 9. BATTELLE MULTISOLID FLUIDIZED-BED COMBUSTOR

Residence Time Range:	
Gas Phase:	Up to about 7 seconds
Solid (or liquid) Phase:	10 seconds to several minutes depending on recycle rate of solids.
Energy Type and Requirements:	Coal, gas, liquids, wastes. Sufficient to heat gases to operating temperature.

V. PERFORMANCE TEST RESULTS

The MSFBC process can be utilized to dispose of, and recover energy from, a variety of wastes such as anthracite refuse, tailings from coal washing operation, wood waste, spent oil shale, municipal solid waste, sewage sludge, scrap rubber, plastic waste, and other industrial wastes, including liquids and gaseous wastes. Pilot-plant facilities are available at Battelle to conduct combustion tests and provide scaleup data for commercial plant design.

VI. COST ESTIMATES

Depends on fuel, scale, and site. Comparable, however, with conventional incineration technology.

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

The process has been tested successfully on a variety of fuels and wastes, such as coal, petroleum coal, municipal solid waste, sewage sludge, wood waste, wood char, plastic waste, and petroleum residuum. The first commercial unit in the United States has been operated successfully in Texas for combustion of coal and petroleum coke to generate steam for use in enhanced oil recovery. A second commercial unit is under construction in Ireland for burning coal and coal-peat mixture to generate process steam.

Design and construction of an integrated commercial plant facility, including materials handling and steam generation, are serviced by licensees.

VIII. FOR MORE INFORMATION

If steam is recovered as part of the process:

Riley Stoker Corporation
9 Neponset Street
Worcester, Massachusetts 01606
Attention: Robert Childs
(617) 852-7100

If heat in a form other than steam is recovered as part of the process:

Struthers Wells
P. O. Box 8
1003 Pennsylvania Avenue West
Warren, Pennsylvania
Attention: James Davis

Bigelow-Liptak Corporation
1250 Maplelawn
P. O. Box 7000
Troy, Michigan 48007-7000
Attention: William Place

If heat recovery is not practiced, please contact:

Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43201
Attention: Jack Conner

for information on possible licensing arrangements.

I. TECHNOLOGY: Circulating Bed Waste Incineration

DEVELOPER: GA Technologies

II. PROCESS DESCRIPTION AND SCHEMATIC

The circulating bed concept is distinct from conventional fluidized beds, which have a fixed bed depth and operate within a narrow range of gas velocities (between the minimum and maximum fluidization velocities). At velocities beyond the maximum, the bed material becomes entrained, with carryover of unburned particles from the combustion chamber. At velocities below the minimum, the bed may slump.

In the circulating bed concept, combustible waste is introduced into a nonmechanical seal along with recirculated bed material from the hot cyclone. Both the fresh feed and the recirculating material are fed into the combustion chamber. A high air velocity 5 to 6 m/sec (15 to 20 ft/sec) entrains both the bed and the combustible waste, which rise through the reaction zone to the top of the combustion chamber and pass into a hot cyclone. The cyclone separates the hot gas from the solids, which are reinjected to the combustion chamber via the return seal as explained above. The hot flue gas passes to a convective gas cooler, then to baghouse filters.

Figure 10 shows a schematic of GA's pilot-scale circulating-bed incinerator system.

III. ADVANTAGES

The developer states the following:

1. Low temperature operation eliminates both ash agglomeration and NO_x emission problems.

   - o Heat removal within the combustion chamber.

2. High turbulence levels, uniform temperatures, and long solid phase residence times insure complete combustion and minimize organic emissions.

   - o >99.99 percent destruction and removal efficiency without afterburners.

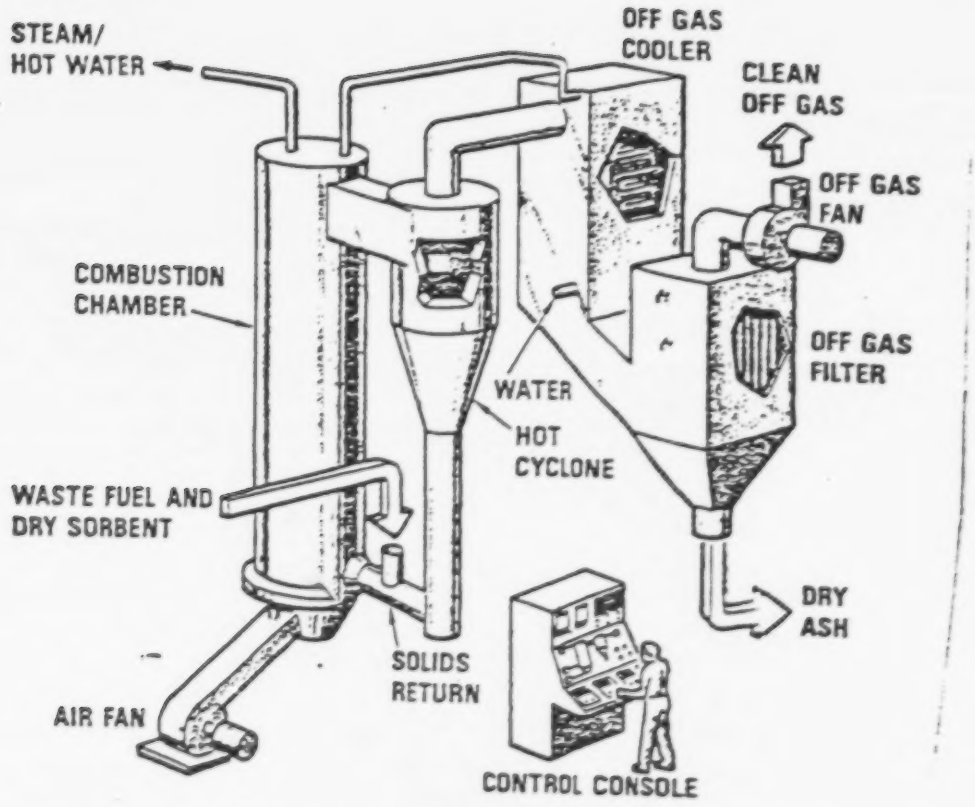


Figure 10. Circulating bed incinerator is configured to turn waste into steam.

- o >99 percent acid gas retention without wet scrubbers and attendant scrubber.

3. Little downstream emission control is required--usually only baghouses.

4. Combustion of low-grade fossil fuels and wastes is demonstrated in sizes up to 250 million Btu/hr.

5. Incinerator accepts solids, liquids, sludges, and slurries in a single-feed port atomizer or multiple-feed injectors.

IV. OPERATING CONDITIONS

Form of Feed Materials: Granular solids, sludges, liquids, slurries.

Temperature Range: 760°-870°C (1400°-1600°F)

Residence Time Range:

Gas Phase: 2-3 seconds

Solid (or liquid) Phase: 10 seconds to 10 hours

Energy Type and Requirements:

Thermal: Sensible and latent heat; self-sufficient up to 85 percent water waste.

Electrical: Blower and feeder operation--approximately 30 HP for 2 MM Btu/h incinerator.

V. PERFORMANCE TEST RESULTS

The developer states more than 7,500 hours of circulating-bed research on a variety of fuels and wastes sponsored by DOE, EPRI, TVA, and a number of commercial sponsors. The test facility was the vendor's 2 MM Btu/h test unit. Specific experience and test results follow (Table 6).

1. More than 10 years of testing (5,000 hours with nuisance wastes and low-Btu fuels, 1,000 hours in fluidized-bed tests, and 1,500 hours in circulating-bed tests.)

2. More than 5 years of modeling combustion efficiency and sulfur capture.

3. Direct participation in commercial applications with TVA-Paducah (fluidized); Gulf Oil-Bakersfield (circulating); and Cal Portland-Colton (circulating).

Additional test data from GA's circulating-bed pilot plant confirm the following high destruction removal efficiencies (DREs) of POHCs:

POHC	DRE (%)	Temperature (°F)
Ethylbenzene	>99.99	1600
Trichloroethane	>99.999	1600
Vinyl chloride	>99.9999	1600
1,2 trans-dichloroethylene	>99.99	1600
1,2 dichloroethane	>99.99	1600

VI. COST ESTIMATES

Basis: 25 million Btu/h--various feeds.

Feed Type	Installed Capital	Annual Operating	Total Per Unit of Feed
Chlorinated organic sludge	$2.0 million	$0.25 million	$60/ton
Contaminated soil	$1.8 million	$0.35 million	$27/ton
Wet sludge	$1.8 million	$0.35 million	$32/ton

VII. STATEMENT OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

While there are over 25 circulating-bed combustors operating worldwide on low-grade fuels, there are currently no circulating-bed units operating commercially as hazardous waste incinerators. The developers have a pilot-scale unit in operation which is capable of incinerating a ton per hour of hazardous waste. The company is also offering to construct commercial-scale facilities. A transportable incinerator is available for onsite demonstration projects.

VIII. FOR MORE INFORMATION

William Rickman
GA Technologies
P. O. Box 85608
San Diego, California 92138
(619) 455-3860

IX. REFERENCES

Performance data is partially documented in "Circulating Bed Incineration of Hazardous Wastes" by William S. Rickman, Nadine D. Holder, and Derrell T. Young, presented at the AIChE 1984 Summer National Meeting, Philadelphia, Pennsylvania, August 19-22, 1984.

Other information was provided by the developer.

TABLE 6. CIRCULATING BED TESTS RESULTS*

Fuel	Cl, F or S (%)	Ash (%)	Heating Value Btu/lb	Ca/Cl_2, Ca/F_2 or Ca/S Molar Ratio	HCl, HF, or SO_2 Retention	NO_x (ppm)	Combustion Efficiency
Oily Water Sludge	4	5	3,000	2.0	99.9+	90	99.99+
Chlorinated Coke Residue	7	18	8,500	2.0	99.5	120	99.9+
Aluminum Potlining	20	30	8,000	1.5	90	95	98+
Chlorinated Organic Liquid	14	2	14,000	1.7	99.9+	40	99.9999+
Ohio No. 6	5.1	13	12,520	1.8	90	280	98.5
Subbituminous Coal	0.9	--	--	2.3	84	170	98.0
Delayed Petroleum Coke	3.7	0.5	15,250	2.0	92	90	97
Syncrude Fluid Coke	6.6	6.6	13,500	1.9	92	220	99
Heavy Bitumen Oil	4.9	0.1	18,100	2.2	88	113	99.8
Diatomite	2.2	77	3,750	2.3	98	200	98.5
High-Ash Brazilian Coal	3.7	44	7,730	0.9	90	250	99.1

*Combustion tests/operation at GA Technologies pilot plant and CBC units designed/built by GA partner in Europe.

I. TECHNOLOGY: Low-Temperature Fluidized Bed

DEVELOPER: Waste-Tech Services, Inc.

II. PROCESS DESCRIPTION

The heart of this system is a fluidized bed, operating at low temperatures, and composed of a mixture of a granular combustion catalyst and limestone. Liquid waste, sludge, or granular solids (with fuel oil as needed) are metered into a pneumatic injection tube which injects the stream into the bottom of the bed. Fluidizing air is forced up through this bed at a high enough velocity such that the bed behaves much like a boiling liquid. Limestone is continuously added to the bed. Bed material is periodically drained from the vessel. Particulate removal is in the form of multiclone system with final flue gas cleanup in a baghouse or other high-efficiency collection system.

Preliminary data suggest that the technology may offer an economic advantage over other systems due to lower operating temperatures, reduced fuel oil requirements, and ability to use standard materials in construction. To date, however, no complete process economics are available. High temperature fluidized beds, 925°-1200°C (1700°-2200°F), are offered or used where the use of catalytic beds is uneconomical or inefficient.

III. ADVANTAGES

The developer states that the fluidized bed can effectively handle the dirt and rock associated with hazardous spills or pond leakage into underlying soils due to a unique air distribution header system which allows for bed letdown across the entire area of the bed.

IV. OPERATING CONDITIONS

Form of Feed Materials: Liquids, sludges or granular solids.

Temperature Range: Low temperature catalytic = 760°-925°C (1400°-1700°F)
High temperature noncatalytic = 925°-1200°C (1700°-2200°F

Residence Time Range:

Gas Phase:	2 seconds for all gas-turbulent flow
Solid (or liquid) Phase:	Variable depending upon life of particle in bed followed by 2-second residence of elutriated particles in vapor stream.
Energy Type and Requirements:	Fuel oil, natural gas, propane. Amount based on waste heating value.

V. PERFORMANCE TEST RESULTS

See Table 7 for typical results.

VI. COST ESTIMATES

50 ft^2 system: Throughput for contaminated soils having 2 percent organics, 5 percent moisture, 9,200 lb/hr.

Operating Labor ($/lb):	$0.0084
Consumables and Utilities:	$0.0138
Nonlabor (capital depreciation, siting cost, maintenance materials, insurance, tax overhead:	$0.0116
Limestone for chlorine removal, waste excavation, ash disposal, etc.:	$0.043
Total Cost:	$150/ton

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

Offered commercially either as a service with Waste-Tech Services owning and operating units, or as a turnkey system.

Market potential--organics, chlorinated and nonchlorinated, solids, sludges, and liquids. Catalysts used dependent on cost tradeoff between supplemental fuel savings and makeup catalyst cost.

VIII. FOR MORE INFORMATION

Waste-Tech Services, Inc.
P. O. Box 736
Idaho Falls, Idaho 83402
(208) 522-0850

TABLE 7. OPERATING CONDITIONS FOR SOIL DECONTAMINATION

	Run No. 1	Run No. 2
Fluidized Bed Temperature (°C)	850	850
Combustion Vessel Exit Temperature (°C)	650	650
Vessel Residence Time (s)	1.3	1.3
Feed Rate:		
Soil (kg/h)	10.5	6.17
Carbon Tetrachloride (kg/h)	0.32	0.40
Dichloroethane (kg/h)	0.035	0.044
Destruction Efficiency %		
Carbon Tetrachloride by Liquid Absorbent	99.985	99.993
by VOST	99.998	99.996
Dichloroethane by Liquid Absorbent	>99.7	>99.7
by VOST	99.998	99.997

8.0 PYROLYSIS

Pyrolysis--processes that break down waste materials into less complex materials through the application of heat in the absence of oxygen. Pyro-conversion units are typically custom designed to process specific types of chemicals rather than as multipurpose waste processing units. Consequently, their use as multipurpose hazardous waste treatment facilities has been very limited. However, one of the pyrolysis processes discussed in this report would be suitable for use as a multipurpose waste processing unit. Advantages of pyrolysis processes are that there is a potential for byproduct recovery, that sludge volumes may be reduced without large amounts of supplementary fuel being used, and that air emissions are usually less for conventional incinerators.

The following processes are included:

Pyrolytic Decomposition--Midland-Ross Corporation
High Temperature Pyrolysis With Oxygen--Russell and Axon

I. TECHNOLOGY: Pyrolytic Decomposition
Continuous - PyroTherm®
Batch - Pyrobatch®

DEVELOPER: Midland-Ross Corporation

II. PROCESS DESCRIPTION AND SCHEMATIC

PyroTherm® Continuous Pyrolysis

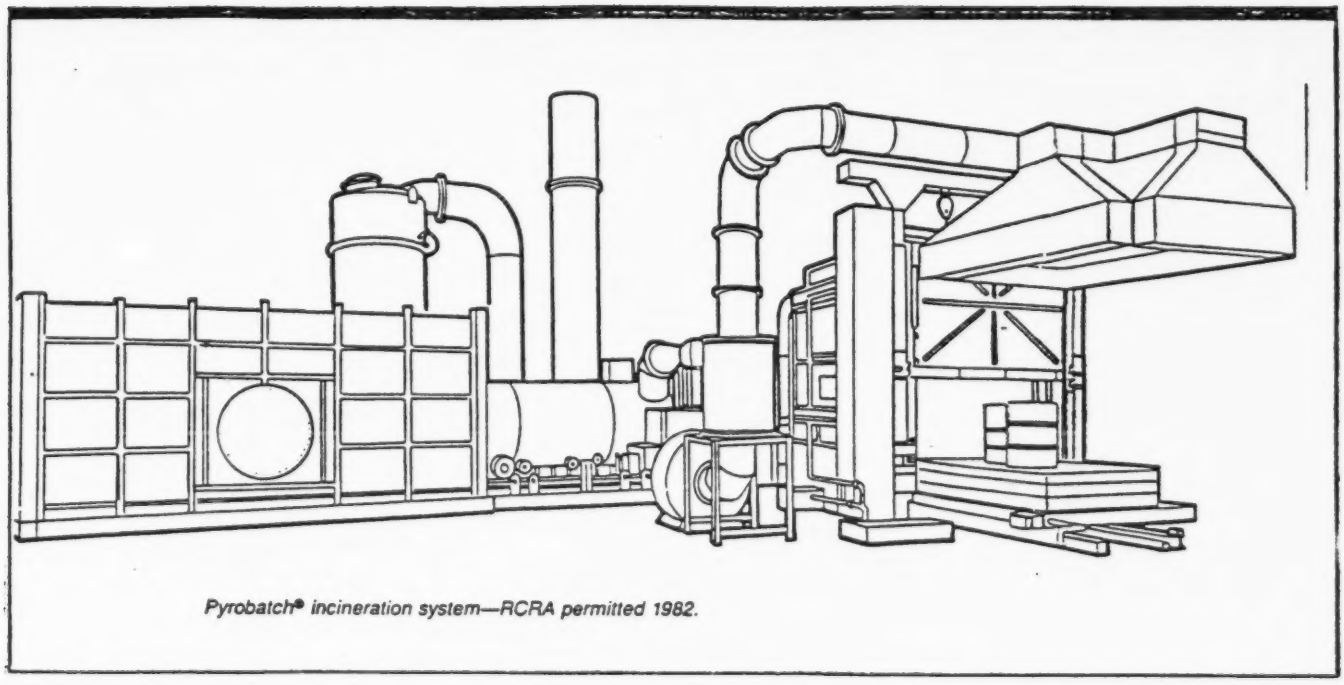
One type of pyrolytic incineration system, designed for granular or liquid materials, includes three major components: a continuous feed furnace, rich fume reactor, and heat recovery device. The furnace is fashioned after high-temperature furnaces used for treating metals and other materials requiring controlled thermal treatment. Waste is continuously fed and passes into an indirect-fired, oxygen-free, pyrolytic chamber. There, the waste is heated to between 540°C (1000°F) and 870°C (1600°F) depending on the type and amount of inert materials in the waste. The heat drives off all volatile components leaving behind the inert materials, and pyrolysis of the waste is normally accomplished in a 15- to 30-minute period of time.

Any remaining inert residue (char) is continuously removed and more feed material is continuously fed in the PyroTherm® furnace. The energy-bearing gaseous fraction then is completely combusted in the rich fume reactor, and the resulting hot gases enter a boiler or other heat recovery device to efficiently recover waste as a usable energy source.

PyroBatch® Systems (Batch Pyrolysis)*

One type of batch pyrolytic incineration system, designed primarily to treat liquids, solids, or semisolids in 55-gallon drums (fiberpak type of steel), is the PyroBatch® System. This type of system consists normally of a batch furnace, a rich fume reactor, and a heat recovery device (if desired). One such system was RCRA permitted in 1984 at McDonnell Douglas Company in St. Charles, Missouri. It is the first "New Hazardous Waste Incinerator" in Region VII U.S. EPA and the State of Missouri.

*See Figure 11.



Pyrobatch® incineration system—RCRA permitted 1982.

Figure 11. PyroBatch® illustration.

PyroBatch® systems are available from 2-drum to 20-drum capacity and are prepiped and wired, skid-mounted, shop-bricked modules available for quick delivery and easy assembly.

III. ADVANTAGES

The developer states the following:

1. Salts and metals (inert materials) with moderate melting points are not liquefied because the pyrolyzer operates at a design temperature below the melting points of most salts and metals.

2. Since the same salts and metals are normally not vaporized, refractory spalling, surface fouling, and formation of inert aerosol condensates are all greatly reduced.

3. Particulate emissions with most types of pyrolyzers are greatly reduced because the waste is not agitated or contacted with turbulent gases during pyrolysis, so particulate cleanup devices in many cases are not needed to meet Federal standards.

4. Waste-borne NO_x is reduced in a pyrolysis atmosphere to N_2 and H_2O. Hence, NO_x emissions from the process are considerably lower.

5. Chlorinated or halogenated materials (e.g., chlorine) typically liberated by thermal treatment of a waste can be absorbed by caustics present in, or added to, the feed prior to pyrolysis. This often leads to a reduction in emissions of HCl and SO_x from 50 to 90 percent.

6. Leaching of metals and salts from the carbonaceous residue (char) is reduced because they are exposed to a reducing atmosphere throughout the process, and they tend to be physically or chemically tied up in the char.

7. Overall, gas cleanup equipment is greatly reduced or not required to pyrolytically treat the same waste materials treated by direct incineration.

IV. OPERATING CONDITIONS

Form of Feed Materials

The developer states the following:

Pyrolytic - Incineration is ideal for processing materials that fall into the following categories:

1. Too viscous to atomize in liquid incinerators, yet too fluid for spreader-stoker incinerators.

2. Low melting point materials that foul heat exchangers, spall refractories, and complicate residue discharge.

3. High residue materials (ash), with easily entrained solids, that would generally require substantial stack gas cleanup.

4. Material containing priority pollutants with excessive vapor pressure at incineration temperatures.

5. Any material, drummed or loose bulk, where controlled thermal treatment is desired to make clean gases for heat recovery or for discharge to the atmosphere.

Pyrolyzer

Temperature Range: 650°-870°C (1200°-1600°F)

Residence Time Range: 15-30 minutes (continuous systems)
4-6 hours (batch systems)

Auxiliary Fuel Requirements: Natural gas, fuel oils, and/or electrically-fired

Rich Fume Incinerator (Reactor)

Temperature Range: 980°-1200°C+ (1800°-2200°F+)

Residence Time Range: 1.0-2.0 seconds

Commercial System

Commercial systems are available as follows:

PyroBatch® Systems . . . . . 1,000 lb/load to 30,000 lb/load

PyroTherm® Systems . . . . . 500 lb/h up

V. PERFORMANCE TEST RESULTS

The RCRA permitted McDonnell Douglas incinerator treats wastes from five POHCs with 50-70 percent chlorinated hydrocarbons. Per the 1984 RCRA Trial Burn, the average DRE of these POHCs was 99.9999 percent (6-9s), HCl was 99.9 percent (3-9s), and particulates were 0.035 grains/dscf (Kaplan, 1982).

Further information is given in Tables 8 and 9.

VI. COST ESTIMATES

The developer states the following:

> "Our cost estimates are proprietary information and are supplied only to customers with whom we have projects. To date, most of our clients' wastes applications are different from one another, hence project capital costs are also different. However, inherent benefits of pyrolytic incineration help our clients realize significant overall project cost reductions relative to direct incineration systems."

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

The technology is offered commercially; several systems are now operational including a 1984 RCRA permitted HWI. Midland-Ross also has a testing facility to offer complete bench and pilot test programs. Our facility has an EPA ID number as a hazardous waste treatment center. Midland-Ross also offers RCRA Permit Assistance Programs for customers requiring RCRA permits.

VIII. FOR MORE INFORMATION

Midland-Ross Corporation
Energy Technology Division
900 N. Westwood
P. O. Box 985
Toledo, Ohio 43696
(419) 537-6444

IX. REFERENCES

Kaplan, Leonard and Herb Short (McGraw-Hill World News). Second Chance for Pyrolysis. News Feature of Chemical Engineering, December 13, 1982, pp. 41-43.

Williams, Irving M., Jr. Pyrolytic Incineration Destroys Toxic Wastes, Recovers Energy. Reprinted from Pollution Engineering, July 1982.

TABLE 8. BENCH TEST RESULTS
Pyrolysis Temperature: 1400°F
Layer thickness: 3/16/ Inch
pH of "as received" No.11 waste: 1.2

Neutralized Sample	pH	Kg of Caustic per kg of "as received" fuel	Pyrolyzing Time (minutes)	Percent Weight Loss	Char Expansion Factor
No. 11/NaOH	4.2	0.0585	2.75	75.0	2.7
	5.2	0.0830	3.00	74.7	5.3
	7.0	0.1075	3.00	74.7	10.7
No. 11$Ca(OH)_2$	4.1	0.06 6	3.50	74.1	2.7
	5.0	0.0789	3.58	74.2	5.3
	7.3	0.0930	2.75	74.8	26.7

See Williams, 1982.

TABLE 9. PILOT TEST RESULTS
Feed: No. 11/$Ca(OH)_2$
Desired layer thickness: 3/16"
Pyrolyzing time: 7.4 minutes in furnace hot zone

	Test 1 (base)	Tests 2, 3, 4	Test 5 (excess O_2)	Test 6
pH of neutralized sample		5.1	5.0	5.0
Pyrolysis temperature (°C)	760	(4.83)	(4.92)	(4.92)
Actual layer thickness (mm)		760	760	815
Duration of test (hours)	1.70	3.68	3.81	3.55
Average feed rate (kg/hr)		2.27	1.85	1.58
Hearth loading (kg/m^2)		11.1	11.4	10.6
Accumulated total feed (kg)		5.2	5.4	5.0
Accumulated total char (kg)		55.8		38.3
Percent weight loss (%)		14.9		11.3
		73.2		70.4

See Williams, 1982.

I. TECHNOLOGY: High-Temperature Pyrolysis with Oxygen

DEVELOPER: Russell and Axon

II. PROCESS DESCRIPTION AND SCHEMATIC

The process, shown schematically in Figure 12, closely resembles that of a blast furnace with environmental control and provision for heat recovery. The process parallels medium-Btu gasification.

In operation, the shaft furnace is initially filled with waste by the rams; municipal solid waste (MSW) is suitable for this. Oxygen flow is started and the furnace is lit. As the temperature rises, molten material collects in the bottom refractory-lined slag pan and continually overflows into a water bath. Then hazardous waste and additional solid wastes are added by the rams to continue the process in steady-state. The hot gases from the melting and burning zone percolate upwards, charring and cracking the material in the shaft furnace above the burn zone. A negative suction pressure maintained by a blower draws these hot gases from the top of the sealed shaft furnace into the water sprays of a scrubber train, with the wastewaters of the scrubber train being collected and recycled, and its overflow water trickled into the melt zone, to be vaporized, or routed to wastewater treatment.

III. ADVANTAGES

The designer (Russell and Axon, Inc./Richard J. Binder, P.E.) claims the following process:

1. Ultra-high temperature, to 1650°C (3000°F).
2. Long residence time, a function of the height of the shaft furnace.
3. No fugitive emissions; all gases, liquids, and solids from the process are retained on site.
4. Gases leaving the process are scrubbed and recovered, to yield a medium-Btu value fuel (250 to 300 Btu/scf). The fuel is used to generate electric power for the liquid air rectification plant, necessary for economical oxygen for the process.

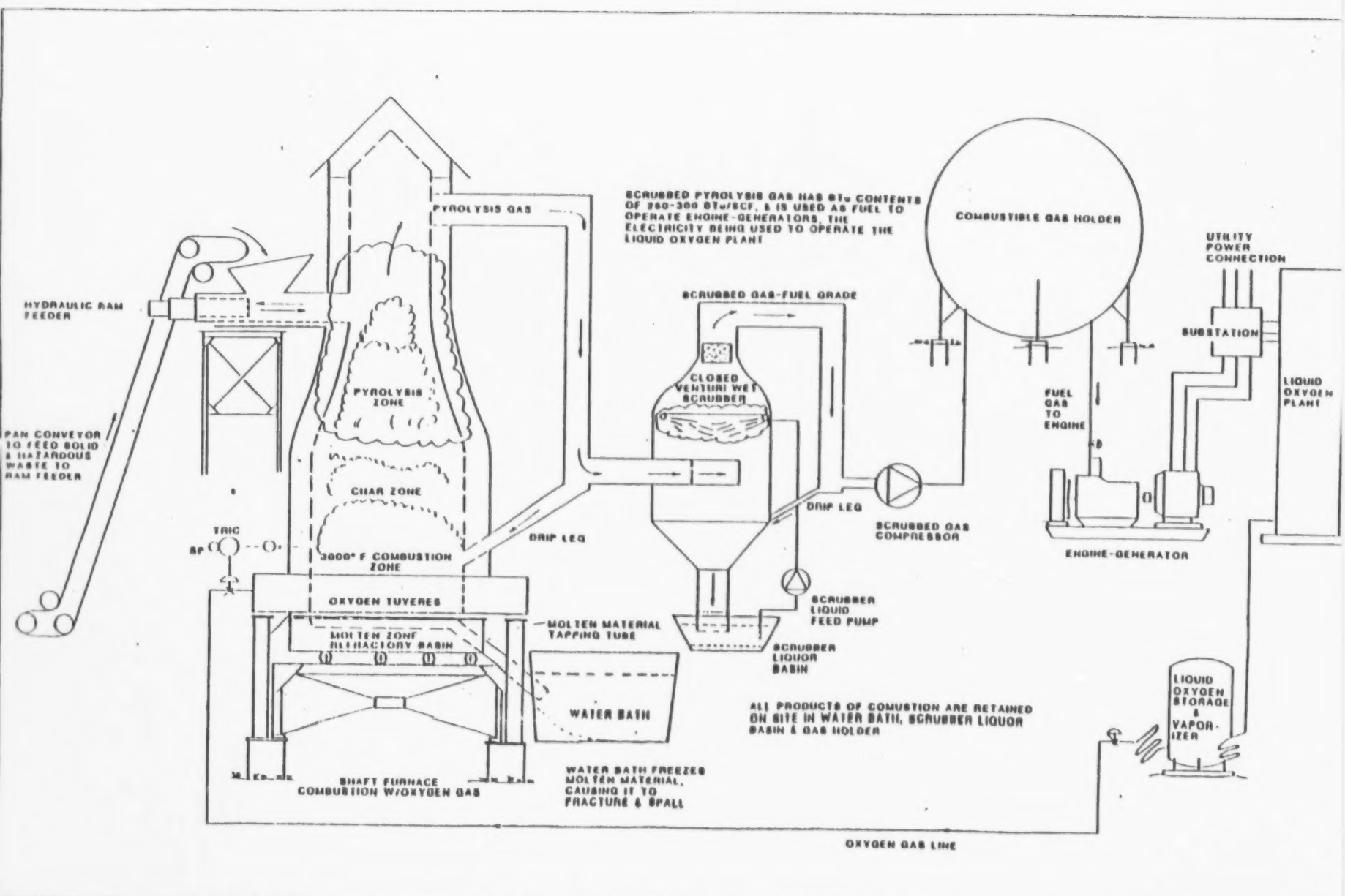

PYROLYSIS GAS
SCRUBBED PYROLYSIS GAS HAS BTu CONTENTS OF 280-300 BTu/SCF, & IS USED AS FUEL TO OPERATE ENGINE-GENERATORS, THE ELECTRICITY BEING USED TO OPERATE THE LIQUID OXYGEN PLANT
COMBUSTIBLE GAS HOLDER
UTILITY POWER CONNECTION
HYDRAULIC RAM FEEDER
SCRUBBED GAS-FUEL GRADE
SUBSTATION
PAN CONVEYOR TO FEED SOLID & HAZARDOUS WASTE TO RAM FEEDER
PYROLYSIS ZONE
CLOSED VENTURI WET SCRUBBER
FUEL GAS TO ENGINE
LIQUID OXYGEN PLANT
CHAR ZONE
DRIP LEG
SCRUBBED GAS COMPRESSOR
TRIC
3000° F COMBUSTION ZONE
DRIP LEG
ENGINE-GENERATOR
OXYGEN TUYERES
SCRUBBER LIQUID FEED PUMP
MOLTEN MATERIAL TAPPING TUBE
MOLTEN ZONE REFRACTORY BASIN
SCRUBBER LIQUOR BASIN
LIQUID OXYGEN STORAGE & VAPORIZER
WATER BATH
ALL PRODUCTS OF COMBUSTION ARE RETAINED ON SITE IN WATER BATH, SCRUBBER LIQUOR BASIN & GAS HOLDER
SHAFT FURNACE COMBUSTION W/OXYGEN GAS
WATER BATH FREEZES MOLTEN MATERIAL, CAUSING IT TO FRACTURE & SPALL
OXYGEN GAS LINE
RUSSELL & AXON
ULTRA-HIGH TEMPERATURE INCINERATOR FOR HAZARDOUS WASTES
RJB
RJB
N.T.S.
JEJ
1/24/84

Figure 12. Ultra-high temperature incinerator for hazardous wastes.

IV. OPERATING CONDITIONS

Form of Feed Materials:	Solids Liquids distributed over solids Oxidizer--gaseous oxygen, essentially pure.
Temperature Range:	800°-1650°C (1500°-3000°F)
Residence Time Range:	Depends on size (height) of shaft furnace and the volume of the solids being incinerated. An average of 15 to 30 minutes residence is practical in normal sizes of equipment.
Gas Phase:	Seconds (to make transit from burn zone through the material moving downwards in the shaft furnace and then to flow into the scrubber). Heat transfer efficiency is high.
Solid Phase:	Depending on height of shaft furnace, 15 to 30 minutes.
Liquid Phase:	Less than for solid phase because of the thermal reduction of viscosity (generally), and ignition and combustion processes occurring in the thin liquid film sections.
Energy Type and Requirements:	Municipal Solid Waste (MSW) is used to serve as a bulking agent and fuel. Hazardous waste, solid or liquid, when added, is a fraction by weight of municipal solid waste charged. (Coal or waste oil may be charged to the furnace, if desired, for its fuel value.)

V. PERFORMANCE TEST RESULTS

No performance test has been run using hazardous materials.

VI. COST ESTIMATES

Capital: $25,000,000 for 120,000,000 Btu/h heat release.

Operating: Using purchased oxygen at $120/ton, delivered to the site, an oxygen use rate of $1800/h is developed when 150 tons per day total throughput is achieved. Alternately, $1500/day of electricity is used to operate a liquid air rectification plant for oxygen production on site. This figure can be reduced to $300/day when scrubbed offgases are used as the energy source to operate engine-generators to power the liquid air rectification plant. A staff of five plus a supervisor are required per shift.

Total Cost Per Unit of Feed: Destruction of 3000 lb/h of hazardous waste, plus 10,000 lb/h of solid waste, with up to 150 tons total per 24 hours of operation, results in an operating cost of approximately $0.60/lb for destruction of hazardous waste, exclusive of cost of debt retirement.

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

The basic process has been demonstrated with municipal solid waste as the Purox process. The modified process herein described is essential where chemical moieties need to be changed so that the presenting chemical form to the incinerator is destroyed, and the residue is available only as carbon dioxide, water, various acids and bases in the scrubber water (permitting equalization), and as complex metallic silicates and borates, etc., in the frozen solids congealed in the water bath.

VIII. FOR MORE INFORMATION

Russell and Axon
319 N. Fourth Street
Suite 700
St. Louis, Missouri 63102-2774
(314) 231-9693

9.0 MOLTEN SALT

Molten Salt--a process in which waste material is injected beneath a bed of molten sodium carbonate for incineration. The process is innovative in that the use of the molten bed requires lower temperatures for waste combustion. Also, the bed acts as a very effective scrubbing medium for acid gases.

The following process is included:

Molten Salt Destruction--Rockwell

I. TECHNOLOGY: Molten Salt Destruction

DEVELOPER: Rockwell International

II. PROCESS DESCRIPTION AND SCHEMATIC

The process consists of injecting the material to be burned with air, or oxygen-enriched air, under the surface of a pool of molten sodium carbonate. The melt is maintained at temperatures on the order of 900°C (1650°F) causing the hydrocarbons of the organic matter to be immediately oxidized to carbon dioxide and water. The combustion byproducts containing such elements as phosphorus, sulfur, arsenic, and the halogens react with the sodium carbonate. These byproducts are retained in the melt as inorganic salts rather than released to the atmosphere as volatile gases. In time, inorganic products resulting from the reaction of organic halogens, phosphorus, sulfur, etc., build up and must be removed from the molten bed to retain its ability to absorb acidic gases. Ash introduced by the waste must be removed to preserve the fluidity of the melt. An ash concentration in the melt of about 20 percent by weight provides an ample margin of safety to maintain melt fluidity. Melt removal can be done continuously or batchwise.

Depending upon the size and design application of the particular unit, the salt in the bed is recovered or disposed of when it becomes excessively laden with ash or products of acid gas reaction. The process can operate at atmospheric pressure or elevated pressure (see Figure 13).

III. ADVANTAGES

The developer states the following:

1. Normal operating temperatures, around 900° (1650°F), are high enough to destroy waste and to maintain the salt molten, but low enough to avoid NO_x emissions.
2. Halogens are retained in the salt bed.
3. Improved reliability, lower cost, and increased waste throughput result from provision for external heat transfer.

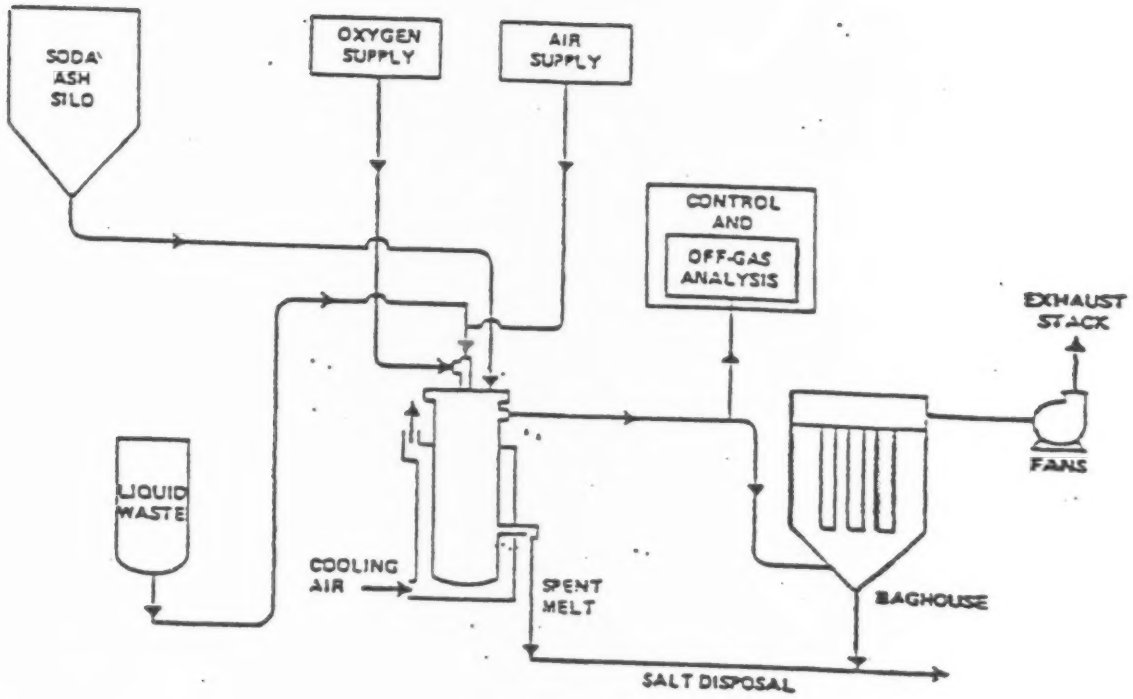


Figure 13. Simplified diagram of the molten salt waste destruction process.

IV. OPERATING CONDITIONS

Form of Feed Materials: Most effective for low ash, low water content, solid or liquid wastes.

Temperature Range: 800°-1000°C (1500°-1850°F)

Residence Time Range:

Gas Phase: ~5 seconds

Solid (or liquid) Phase: Hours

Energy Type and Requirements: Fuel to burn waste (if not combustible), electric power for blowers.

V. PERFORMANCE TEST RESULTS

Typical bench-scale and pilot-scale test results are given in Tables 10 and 11.

VI. COST ESTIMATES

Not available.

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

Since beginning the development of molten salt combustion technology in 1969, based on earlier molten salt studies, Rockwell has constructed several units of varying sizes. The company has conducted extensive tests in two sizes of units; bench-scale combustors for feeds of up to 10 lb/h of wastes, and a pilot-scale unit for feeds of up to 250 lb/h of wastes.

VIII. DEVELOPER INFORMATION

Rockwell is currently engaged in discussions with potential licensees with regard to demonstration and commercialization of the process.

Rockwell International
Environmental and Energy Systems Division
8900 De Soto Avenue
Canoga Park, California 91304
(213) 700-8200

TABLE 10. SUMMARY OF PILOT-SCALE TEST RESULTS

	HCB	Chlordane
Combustor Feed Rate (lb/hr)	20.9 - 122.0	12.1 - 32.7
Combustor Offgas		
mg/m^3	2.7×10^{-4} - 7.1×10^{-2}	5.3×10^{-3} - 6.8×10^{-2}
ppmv	2.3×10^{-5} - 6.1×10^{-3}	3.2×10^{-4} - 4.1×10^{-3}
Baghouse		
mg/m^3	$<6 \times 10^{-6}$ - 1.6×10^{-4}	$<3.6 \times 10^{-4}$ - $<4.4 \times 10^{-3}$
ppmv	$<5.2 \times 10^{-7}$ - 1.4×10^{-5}	$<2.1 \times 10^{-5}$ - $<2.6 \times 10^{-4}$
Spent Melt (ppmv)	0.001 - 0.104	0.0044 - 1.2
NO_x (ppmv)	70 - 125	0.5 - 630
HC (ppmv)	35 - 110	0.4 - 60
Particulate (mg/m^3)	$<6.2 \times 10^{-3}$ - 0.107	4.1×10^{-3} - 1.75×10^{-2}
DRE (%)	11-9's - 9-9's	8-9's - 7-9's

Note: The pH of the liquid in a small sampling scrubber in the offgas line remained basic throughout the test indicating essentially no HCl emission.

TABLE 11. DESTRUCTION EFFICIENCIES AND PCB EMISSIONS FOR FIVE PCB DESTRUCTION RUNS--BENCH-SCALE

Test Number	Temperature (°C)	Destruction Efficiency (%)	PCB in Offgas* (mg/m^3)
1	912	99.99971	0.23
2	903	99.99932	0.57
3	851	99.99957	0.38
4	801	99.99940	0.53
5	754	99.99917	0.78

*Does not include PCB found in melt.

10.0 ADVANCED INCINERATORS

Advanced Incinerators--processes that incorporate improvements over conventional incinerators but which maintain the essential principles of conventional incinerators. The report contains three such systems--a liquid injection system incorporating fuel feed to promote extremely intensive mixing and two systems using rotary kilns. These systems are illustrative of the improvements being made in conventional incinerator designs.

The following processes are included:

CONSERTHERM Rotary Kiln Oxidizer--Industronics, Inc.
Fast Rotary Reactor--PEDCo Technology Corporation
"CYCLIN" Cyclone Incinerator--IGT

I. TECHNOLOGY: CONSERTHERM Rotary Kiln Oxidizer

DEVELOPER: Industronics, Inc.

II. PROCESS DESCRIPTION

The CONSERTHERM is a modular, controlled-air incinerator incorporating the following components: an auger-shredder feed or screw feed (and on many applications a liquid/sludge feed), a rotary kiln primary oxidation chamber, secondary oxidation chamber, dry ash removal system, breeching, stack, and heat recovery boiler. Depending on the specific application, a CONSERTHERM System may also include a prefeed waste handling system, air pollution control device(s), and turbine generating equipment. In operation, waste is placed in a hopper and continuously rough-shredded and fed into the rotary kiln. Liquids and sludges are injected continuously, without the need for atomization.

Primary oxidation occurs in the rotary kiln which is a refractory lined drum having no rams, grates, or air injection nozzles. Retention time is controlled by varying kiln rotation speed to the desired extent of reaction for the waste being processed.

Secondary oxidation occurs in the secondary oxidation chamber which provides relatively high operating temperatures, 1200°-1200°C (2200°-2400°F), and a long retention time is achieved in the secondary chamber.

Additional modules include the dry ash removal system and the computer control system, which controls preheat cycle of the primary and secondary chambers, waste material feed rate, combustion air, alarm functions, and normal and emergency shutdown.

III. ADVANTAGES

The developer states the following:

1. Rugged and dependable construction.
2. Capability of cofeeding liquids, sludges, and solids.
3. High turndown ratios.

4. Good control of retention time.

5. Good approach to complete combustion.

6. The ease of permitting which results from the test burn procedure with regulatory agencies.

7. Self-sustaining operation on high energy value materials (approximately 4000 Btu/lb).

IV. OPERATING CONDITIONS

Form of Feed Materials: Liquid, sludge, and solid.

Temperature Range: Normally 1200°-1300°C (2200°-2400°F) in secondary chamber.

Residence Time Range:

Gas Phase: POC - 1 second; SOC - 2 seconds.

Solid (or liquid) Phase: SOC - 2 seconds.

	HHV-100	HHV-200
I.D. Fan	20 HP	30 HP
Auger Feed	30 HP	40 HP
Kiln, Ash Conveyor	5 HP	5 HP
Bypass, Dump Doors		
Sensible Heat for Warmup	5 million/h	10 million/h
Heat Loss	2.5%	2%

Energy Type and Requirements

Thermal: Sensible heat and heat loss.

Mechanical or Electrical: Kiln rotation, auger feeder, etc.

V. PERFORMANCE TEST RESULTS

To date a number of hazardous and nonhazardous wastes have been tested in this system with excellent results. (A partial listing of materials tested to date, and test results are in Table 12.) Test burns are conducted to collect a variety of information which includes:

- Feed Material Characteristics
- Ignition and Burn Characteristics
- Incineration Characteristics
- Volume and Weight Reductions
- Ash Residue Characteristics

- o Particulate Levels
- o Acid Formation Levels
- o Destruction and Removal Efficiencies on Organic Hazardous Constituents

VI. COST ESTIMATES

	HHV-100 (10 MM Btu/h)	HHV-200 (20 MM Btu/h)
*Capital Equipment	$367,198	$554,729
Installation	44,064	666,567
Maintenance and Parts	3%	3%
**Electrical ($0.55 kWh)	10,560/yr	15,840/yr
**Auxiliary Fuel ($0.65/therm)	2,229/yr	3,714/yr

Approximate Total Cost: $20/ton

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

Industronics manufactures 20 standard-size systems with two available kiln lengths for low or high moisture materials.

VII. DEVELOPER INFORMATION

Industronics, Inc.
489 Sullivan Avenue
P. O. Box G
South Windsor, Connecticut 06074-0956
(203) 289-551

IX. REFERENCES

Industronics, Inc. 1983. Summary of Test Burn Results. Industronics, Inc., 489 Sullivan Avenue, South Windsor, Connecticut 06074. October 14, 1983.

*Based on 5-day week; 250-day year operation.
**Capital included auger/sizer, kiln, secondary oxidation chamber, 150 psi boiler, soot blower, ash belt, scrubber with neutralization and hazardous waste instrumentation and controls, and duct and stack work.

TABLE 12. CONSERTHERM TEST BURN RESULTS

Material	Feed Rate (lbs/hr)	Weight Reduction (%)	Particulate Emissions (gr/dscf)
PLASTICS			
Polyester	120	99.2	.003
PVC	144	89	.024
Phenolic Resins	283	93	.026
			.003
Fluff	530	50	.0007
Latex Polymer	230	91	.13
PET Bottles	154	98.5	.073
Carpet Remnants	148	90	.041
SLUDGES			
Automobile Engine Shredding Sludge	-	-	.0007
Machining Sludges	-	20	.001
Sewage	-	-	.08
Polymer Sludges	-	97	.048
Organic Sludges	-	97	.083
FOSSIL FUELS			
Wood Chips	-	98.7	.031
Sawdust	252	-	-
Waste Oil	-	-	-
Waste Oil and Steel Wool	-	48	-
Coal	-	-	-
PROCESS			
Pulp Liquor Salt Refining	-	-	.02
Molding Sand	-	-	-
Cutting Fluids--Was/Oil/ Solvent Mixture	-	99	.45
Vanadium Pentoxide	-	89	.005 grns
HAZARDOUS WASTE			
Organics	-	-	.059
Solvent Mixtures	-	-	-
Metal Hydroxide Sludge	-	80	-
SOLVENTS			
Turpentine	-	-	.0003
ASBESTOS			
Milled/Dyed Asbestos	-	-	-
Asbestos in Brake Linings	-	-	-
TIRES	66-160	75	.0009
TRASH			
Paperback Books	280	93	.05
Shredded and Nonshredded Packaging Paper	220	-	.006

TABLE 12. (Continued)

Material	Feed Rate (lbs/hr)	Weight Reduction (%)	Particulate Emissions (gr/dscf)
TRASH (Continued)			
Wallpaper	173	86	-
Cardboard	305	90	.023
Municipal Solid Waste	360	74.1	.03
Industrial Waste	300	92	.031
Hospital Waste	249	87.8	.076
PRECIOUS METALS			
Gold Bearing Floor Tiles	-	50	-
Printed Circuit Boards	-	31	-
Electronic Equipment	-	30	.023 grns
Paper and Mylar Film	165	91.5	.002 grns
Micro Film	120	98	-

Industronics, Inc. (1983)

I. TECHNOLOGY: Fast Rotary Reactor; Incinerator Applications

DEVELOPER: PEDCo Technology Corporation

II. PROCESS DESCRIPTION AND SCHEMATIC

The "fast" rotary reactor (shown schematically in Figure 14) generally consists of a hollow cylinder which may be single- or multi-compartmental, depending upon the application, rotating at 8 to 20 revolutions per minute. This is considerably faster than the conventional rotating kilns to which it bears a superficial resemblance. The latter generally operate at less than 1 revolution per minute.

The PEDCo Fast Rotary Reactor provides excellent contact between solids and gases by cascading the solids through gases and thereby effecting high rate of heat transfer. Solids can be readily recycled or transferred from one compartment to another and gases can be introduced or withdrawn as desired. This provides great flexibility and allows designs to be optimized for a particular processing operation.

Cascading solids through the surrounding media insures complete mixing and intimate contact. This provides the mechanism to transfer heat between the substances. Also, desired solid/gas reactions, such as combustion and SO_2 absorption, are enhanced by the cascading.

The drawing (Figure 14) shows the cascading action of the particles when the unit is operated at various speeds. When the unit operates at speeds producing a centrifugal force of less than 0.05 G*, no cascading occurs and article contact is limited. Cascading increases with speed of rotation. Maximum cascading, producing greatest solid/gas contacting, occurs at approximately 0.5 G. When the centrifugal force approaches 1.0 G, cascading is suppressed as particles are forced against the walls of the cylinder.

*G is the force of gravity; 1 lbf/lbm or 980 dynes/g.

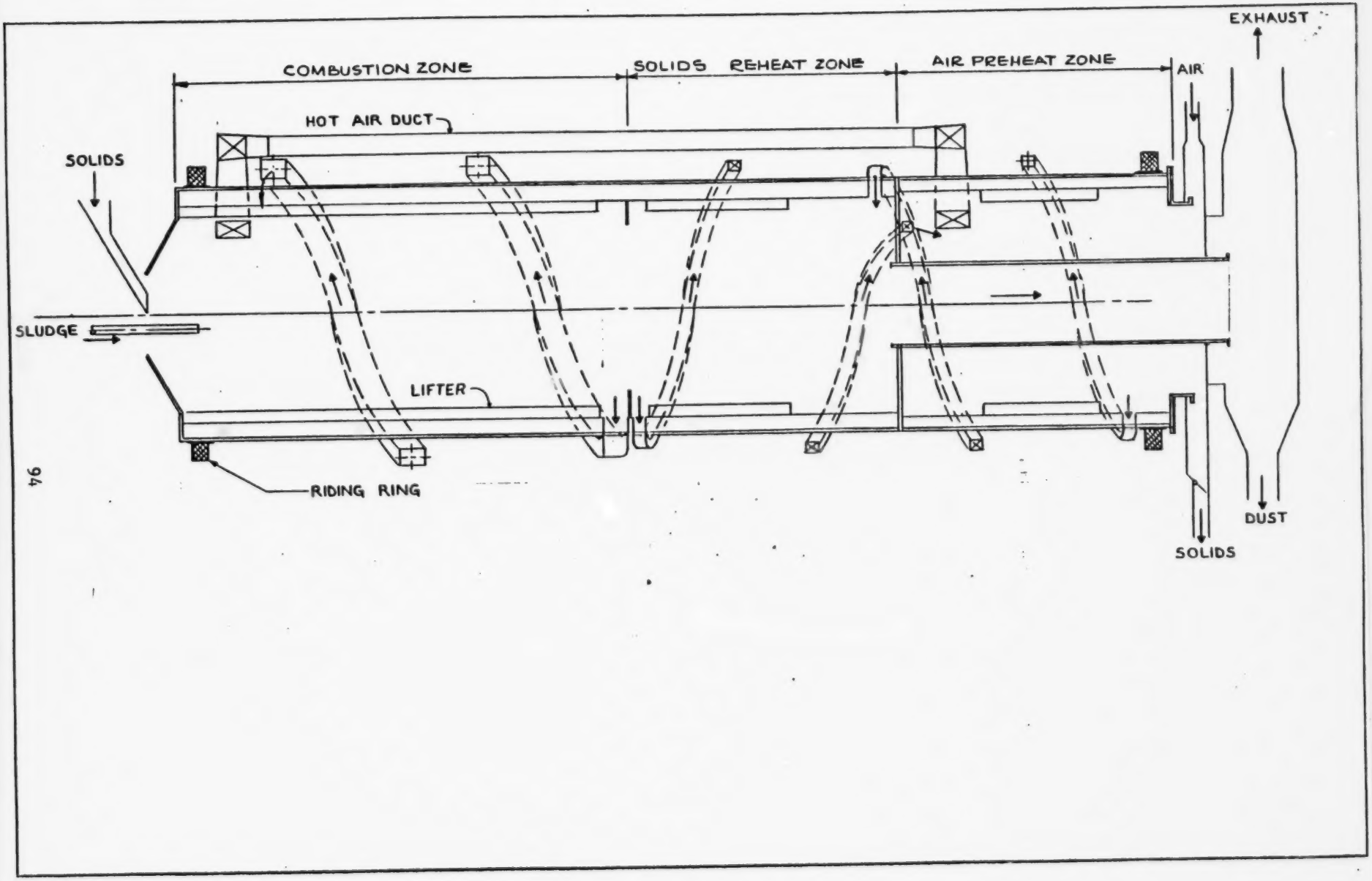


Figure 14. Rotary incinerator with air preheat.

Reactor internal design is varied to provide a variety of features specific to each application. Material transport, retention times (both solids and gases), cascading, backflow, gas/solids contact, temperature control, compartmenting, reaction kinetics, and a variety of combustion conditions can be controlled to desired levels by varying the design features.

III. ADVANTAGES

The developer states the following advantages:

1. Reliability and dependability, being firmly grounded in well-established rotary kiln and dryer technology.
2. High thermal efficiency resulting from effective heat recovery.
3. Ease of adjustment and control of incineration conditions.
4. Handles wide variations in feed rate; e.g., high turndown ratio.
5. Easy to cofeed limestone or other adsorbent for gas phase emission control.

IV. OPERATING CONDITIONS

Form of Feed Materials: Solids, gases, solid-laden gases, sludges, and liquids. (Predominantly solids and sludges).

Temperature Range: Up to 870°C (1600°F).

Residence Time Range:

Gas Phase: 2 to 6 seconds.

Solid (or liquid) Phase: 10 to 30 minutes

Energy Type and Requirements:

Type: Thermal; a wide variety of combustible wastes, or supplementary fuels (coal, oil, grease) to supply sensible heat and heat losses.

Mechanical or electrical to rotate reactor.

Requirement: Thermal; typically ~2000 Btu/lb of solid feed for autogenous operation.

Electrical: Typically 10 to 15 HP per million Btu of capacity.

V. PERFORMANCE TEST RESULTS

A PEDCo rotary incinerator pilot plant 2 ft 4 in. ID x 18 ft long has been operated successfully on a variety of sludges and on high sulfur coal.

The more significant results obtained to date are shown in Table 13.

VI. COST ESTIMATES

Not available.

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

Engineering of commercial-sized incinerators is underway.

VIII. DEVELOPER INFORMATION

Rotary incinerators are available from:

PEDCo Technology Corporation
11499 Chester Road
Cincinnati, Ohio 45246-1000
(513) 782-4500

TABLE 13. PEDCo ROTARY INCINERATOR PILOT PLANT DATA

Type Feed	Feed Rate lb/h	Approximately Btu/lb	Cooling Water	Air Rate cfm	Combustion Temperature °F	Exit Gas Temperature °F	Exit Gas Composition O_2 %	CO ppm	Other ppm
Emulsion Sludge	90	2,000	0	150	1600	1140	10	2	<1 HC
Acrylic Emulsion	210	5,000	300	240	1550	1080	8.0 7.5	2 40	
Chlorinated Aromatics	15	11,000	~80	150	1575	1000	10	NA	13 HCl
			Initial Bed Contained 130 lb Limestone						
Ohio Coal 4.3% S	40	13,000	~200	150	1575	1000	12	NA	5 SO_2
			Initial Bed Contained 200 lb Limestone						

NA = Not Analyzed.

I. TECHNOLOGY: "CYCLIN" Cyclone Incinerator

DEVELOPER: Institute of Gas Technology, Developer
York-Shipley, Inc., Design and Manufacturing

II. PROCESS DESCRIPTION AND SCHEMATIC

The CYCLIN cyclone incinerator is a cylindrical shaped combustion chamber into which premixed fuel, waste, and air are introduced tangentially so as to induce potential-like flow (in which tangential velocity varies inversely with radial position). The resulting high-shear field provides intense mixing and complete combustion. Figure 15 is a diagram of a pilot-scale incinerator, showing interchangeable sections for increased versatility.

III. ADVANTAGES

The developer states the following:

1. Stable and energy efficient combustion.
2. Small combustion volume and focusing of heat to waste.
3. Centrifugal separation of ash and slag, resulting in clean exhaust gases.
4. Long refractory life from wall cooling.
5. Low temperature combustion, resulting in smaller fuel requirements.

IV. OPERATING CONDITIONS

Form of Feed Materials:	Gases or atomized liquids
Temperature Range:	870°-1650°C (1600°-3000°F)
Residence Time Range:	Depends on the type of waste to be incinerated.
Pressure Drop:	10"-20" wc
Energy Type and Requirements:	Natural gas or liquid fuel, sensible heat to operating temperature.

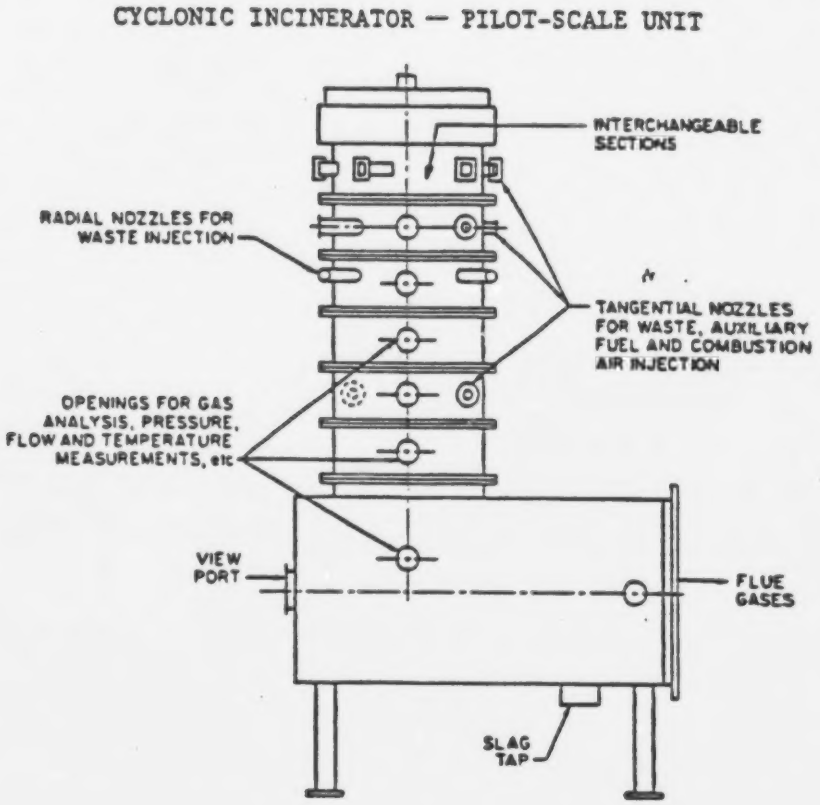

CYCLONIC INCINERATOR — PILOT-SCALE UNIT
INTERCHANGEABLE SECTIONS
RADIAL NOZZLES FOR WASTE INJECTION
TANGENTIAL NOZZLES FOR WASTE, AUXILIARY FUEL AND COMBUSTION AIR INJECTION
OPENINGS FOR GAS ANALYSIS, PRESSURE, FLOW AND TEMPERATURE MEASUREMENTS, etc
VIEW PORT
FLUE GASES
SLAG TAP

Figure 15. Overall view of the pilot-scale CYCLIN process waste incinerator.

V. PERFORMANCE TEST RESULTS

Performance testing of a pilot-scale unit demonstrated stable combustion of 15 gal/h of a liquid waste containing 35 to 55 percent solids concentration. The heat contribution ratio of waste to natural gas averaged 60:40 (on a Btu basis). Major operating parameters during testing included a 0.8×10^6 Btu/hr total firing rate, 1175°C (2150°F), combustion temperature, and specific heat release of 250,000 Btu/h per cubic foot of combustion volume. A 48-hour run demonstrated relatively small ash accumulation within the cyclonic chamber (Crimmins et al., 1984).

VI. COST ESTIMATES

Function of capacity, heating value of waste, and required residence time.

Capital:	Estimated capital cost should be less than $1/4 million for unit incinerating about 400 gal/h of above waste.
Operating:	$30 per hour for above facility.
Total Cost:	$20-$30/ton.

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

The developer is offering engineering and fabrication of the entire system, including heat recovery, on a turnkey basis. One complete demonstration system is in startup and two commercial size units have been ordered.

VIII. DEVELOPER INFORMATION

Institute of Gas Technology (Headquarters)
3424 South State Street
Chicago, Illinois 60616
(312) 567-3650

IX. REFERENCES

Crimmins, J., M. Khinkis, V. Kunc, J. Korenberg, and C. Reider. 1984. Development and Commercialization of an Efficient Cyclonic Incinerator for Wastes. Institute of Gas Technology and York-Shipley, Inc. Paper presented at the Symposium on Energy From Biomass and Wastes VIII, Lake Buena Vista, Florida, January 30-February 3, 1984.

11. ELECTRIC REACTOR

Electric Reactor--processes that pyrolyze waste contaminants off particles such as soil through use of an electrically heated fluid wall reactor. These units have been used successfully in other chemical processes and are just beginning to be adopted for waste destruction. The units, especially the portable versions of the processes, appear to offer a very different and potentially valuable thermal option for hazardous waste treatment.

The following processes are included:

High-Temperature Fluid Wall--Thagard Research Corporation
Advanced Electric Reactor--Huber

I. TECHNOLOGY: High-Temperature Fluid Wall (HTFR) Reactor

DEVELOPER: Thagard Research Corporation

II. PROCESS DESCRIPTION AND SCHEMATIC

The HTFR is basically a hot column through which finely divided material is dropped, undergoing pyrolytic decomposition and chemical reaction during its fall through the hot zone. The reactor operates at temperatures around 2200°C (4000°F); heating is by electric resistance heaters whose placement and geometry is shown in the process schematic, Figure 16.

At these temperatures, heat transfer is dominated by radiation rather than by conduction or convection, and is consequently quite rapid. Vitreous solid waste will quickly melt and foul equipment surfaces unless provision is made to prevent this action. Such is done by providing a porous inner wall through which a purge gas is passed in order to deflect the reacting stream from the hot surfaces.

III. ADVANTAGES

The developer states the following:

1. Reduced residence times, hence reactor costs, by virtue of rapid radiative heat transfer.
2. Prolonged reactor life by virtue of inert gas blanketing.
3. Complete destruction of waste materials by virtue of high temperatures.
4. Production of a medium-Btu combustible gas by virtue of operating in a reducing environment.
5. Production of output solids with designable water leach characteristics allowing processing of heavy metals.

IV. OPERATING CONDITIONS

Form of Feed Materials: Granular solids (-20 mesh -100 mesh). Also 200 scfm N_2 for wall blanketing in 12-inch I.D. reactor.

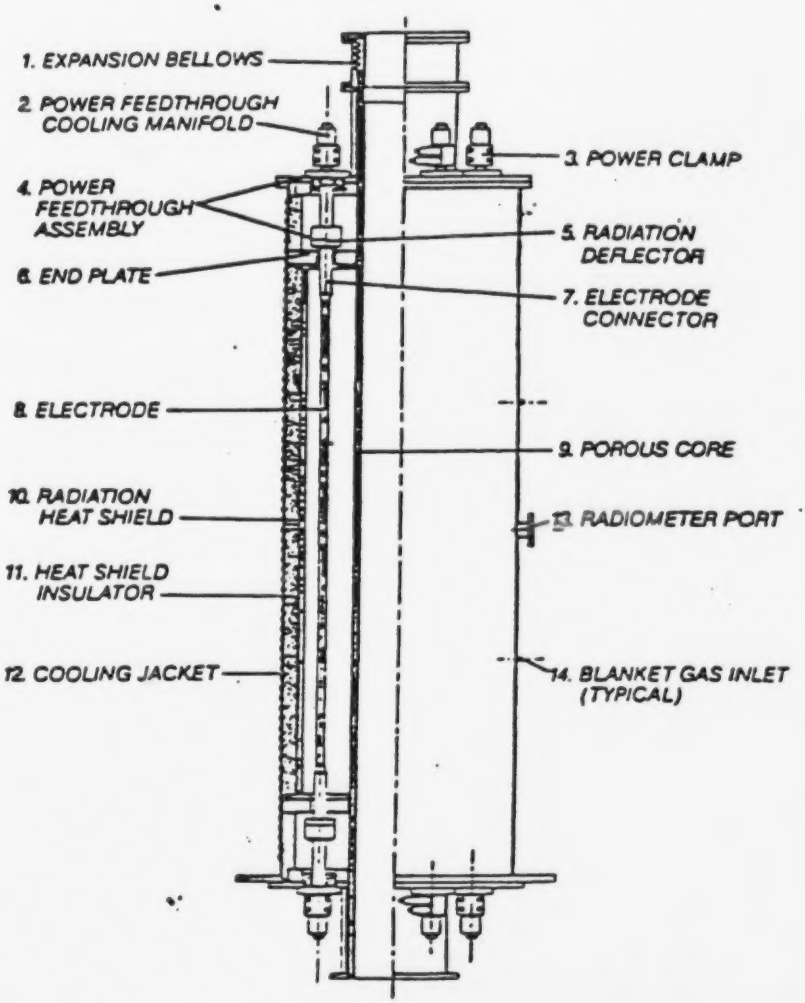


Figure 16. Vertical cross section of a typical fluid-wall reactor.

Temperature Range:	2200°C (4000°F)
Residence Time:	
Gas Phase:	0.1-1.0 second
Solid (or liquid) Phase:	(entrained) 0.1-1.0 second
Energy Type and Requirements:	Approximately 400 kWh electrical energy per ton of feed material

V. PERFORMANCE TEST RESULTS

Four volatile chlorinated hydrocarbons (dichloromethane; 1,1,1-trichloroethane; carbon tetrachloride; and Freon-12 [dichlorodifluoromethane]) and one nonvolatile chlorinated hydrocarbon (hexachlorobenzene) have been decomposed in the High-Temperature Fluid-Wall (HTFW) Reactor in bench-scale tests to assess the applicability of the device for efficient destruction of these particular compounds. PCBs have also been thermally destroyed with high efficiency. Other operators of fluid-wall reactors have reported DREs in excess of 99.9999 percent.

The hexachlorobenzene, loaded onto a solid radiation target, exhibited high (>99.9999 percent) destruction efficiency, while the vapors (which could be heated only by secondary thermal conduction from solid radiation target) exhibited destruction efficiencies related inversely to the compound heats of formation, indicating that vapor-phase reaction temperatures were lower than the solid reaction. Destruction efficiencies ranged from 99.999965 percent for dichloromethane to 84.99 percent for Freon-12. Heat transfer analysis indicated that vapor heating is dependent on the solid particle density, and that efficient heating (and destruction) of vapors can be achieved simply by increasing the particle density.

Additionally, a parametric economic analysis of waste disposal has been performed showing that a classical engineering cost tradeoff between landfill and destruction technology (using the HTFW Reactor as an example) is seen at a 100-mile haul to secure landfill vs. a 100-TPD destruction capability onsite (Horning and Matovich, 1983).

Thermal destruction of sodium nitrate waste to levels >98 percent have been consistently achieved with low NO_x emissions (Meile and Johnson, 1982).

VI. COST ESTIMATES

Capital: $1-5 MM depending on size and peripherals.

Operating: $4,000-5,000/day for 25-50 ton capacity.

Total Cost: $1000/ton

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

Pilot plant; commercial 25-50 TPD fixed and mobile units constructed and available for test and operation.

VIII. DEVELOPER INFORMATION

Thagard Research Corporation is not itself engaged in hazardous waste treatment except for consultation to its licensees. One such licensee is Vulcan Resources, Ltd., of Miami, Florida, which owns a fully-mobile 12-inch reactor system.

Thagard Research Corporation
3303 Harbor Boulevard
Suite F-4
Costa Mesa, California 92626
(714) 556-4470

IX. REFERENCES

Horning, A. R., and E. Matovich. 1983. Thermal Destruction of Chlorinated Hydrocarbons with a High-Temperature Fluid-Wall Reactor. Grant No. R808908, Reference No. TRC260. Prepared for U.S. Environmental Protection Agency, Cincinnati, Ohio. March 30, 1983.

Meile, L. J., and A. J. Johnson. 1982. Waste Generation Reduction-Nitrates FY 1982 Status Report. Rockwell International Energy Systems Group, Rocky Flats Plants. Under UC-70 Nuclear Waste Management DOE/TIC-4500 (Rev. 71), RFP-3465.

I. TECHNOLOGY: Advanced Electric Reactor

DEVELOPER: J. M. Huber Company

II. PROCESS DESCRIPTION AND SCHEMATIC

The Huber Technology Group (HTG) process is based on the Advanced Electric Reactor (AER) which is shown in Figure 17. The reactor employs a new technology to rapidly heat materials to temperatures in the range of 4000°F using intense thermal radiation in the near-infrared region. The reactants, which can be in gaseous, liquid, or solid form, are isolated from the reactor core walls by means of a gaseous blanket formed by flowing nitrogen radially inward through the porous core walls. Carbon electrodes are heated and in turn heat the reactor core to incandescence so that heat transfer is accomplished by thermal radiative coupling from the core to the feed materials. The only feed streams to the reactor are the solid, liquid, or gaseous wastes and the blanket gas, nitrogen. Destruction is accomplished by pyrolysis rather than oxidation. Therefore, typical products produced by incineration, such as carbon monoxide, carbon dioxide, and oxides of nitrogen, are not formed in significant concentrations. The principal products of soil-borne PCB destruction using the Huber process are H_2, Cl_2, HCl, elemental carbon, and a granular, free-flowing, solid-derived material. Figure 18 is a simplified process diagram of the HTG process. For solid waste treatment, the solid feed stream is introduced at the top of the reactor by means of a metered screw feeder connecting the air-tight feed hopper to the reactor. Nitrogen is introduced primarily at two points in the reactor annulus formed by the external containing vessel and the porous graphite core which creates the fluid wall. The solid feed passes through the reactor where pyrolysis occurs at temperatures above 2200°C (4000°F). After leaving the reactor, the product gas and waste solids pass through two post-reactor treatment zones (PRTZ). The first PRTZ is an insulated vessel to provide additional high temperature (in excess of 1100°C, 2000°F)) and residence time (5 to 10 seconds) while the second PRTZ is water-cooled. It also provides additional residence time (approximately 10 seconds) but primarily cools the gas to less than 540°C (1000°F) prior to downstream particulate cleanup.

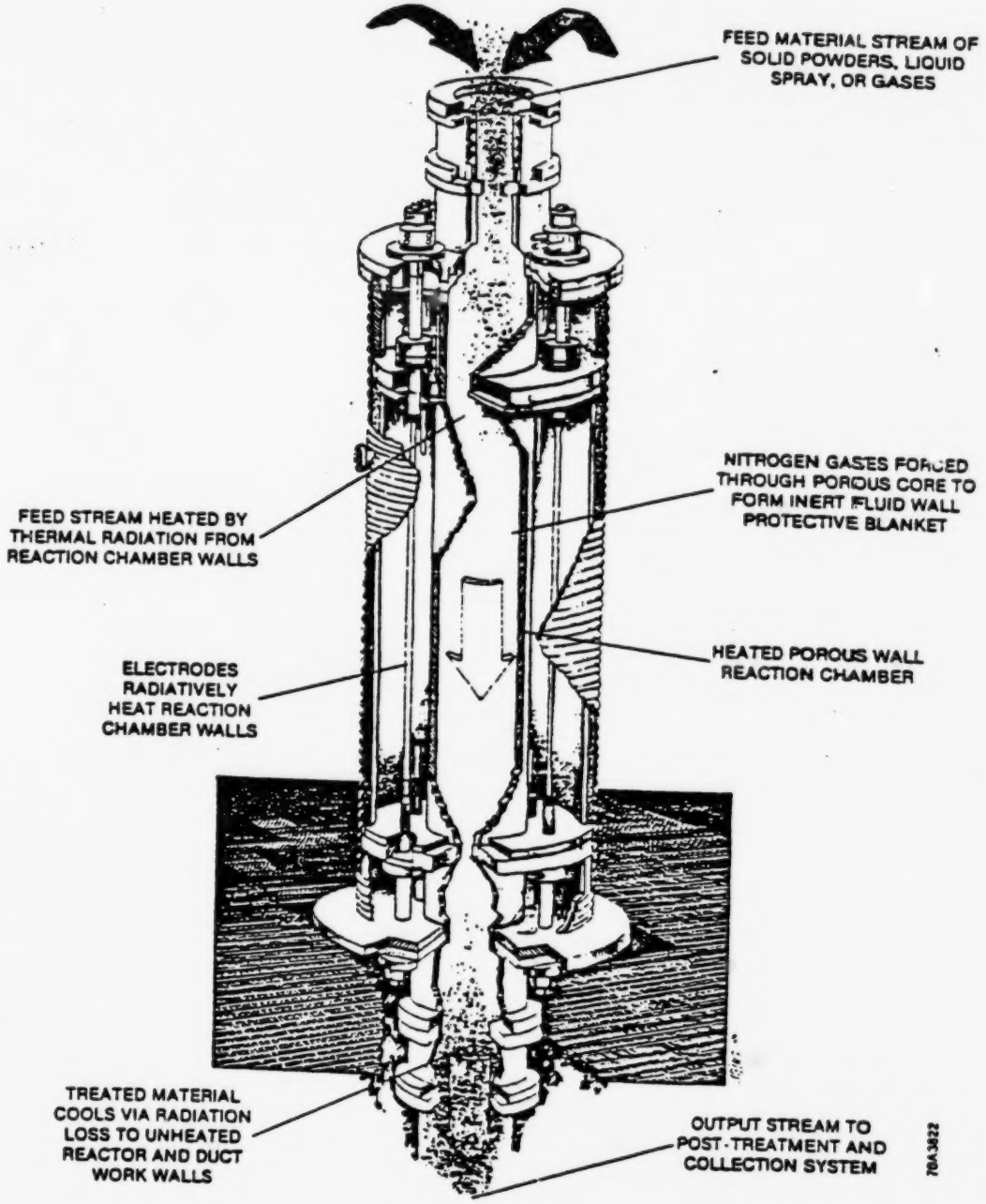

FEED MATERIAL STREAM OF SOLID POWDERS, LIQUID SPRAY, OR GASES
NITROGEN GASES FORCED THROUGH POROUS CORE TO FORM INERT FLUID WALL PROTECTIVE BLANKET
FEED STREAM HEATED BY THERMAL RADIATION FROM REACTION CHAMBER WALLS
HEATED POROUS WALL REACTION CHAMBER
ELECTRODES RADIATIVELY HEAT REACTION CHAMBER WALLS
TREATED MATERIAL COOLS VIA RADIATION LOSS TO UNHEATED REACTOR AND DUCT WORK WALLS
OUTPUT STREAM TO POST-TREATMENT AND COLLECTION SYSTEM
70A3822

Figure 17. Advanced electric reactor.

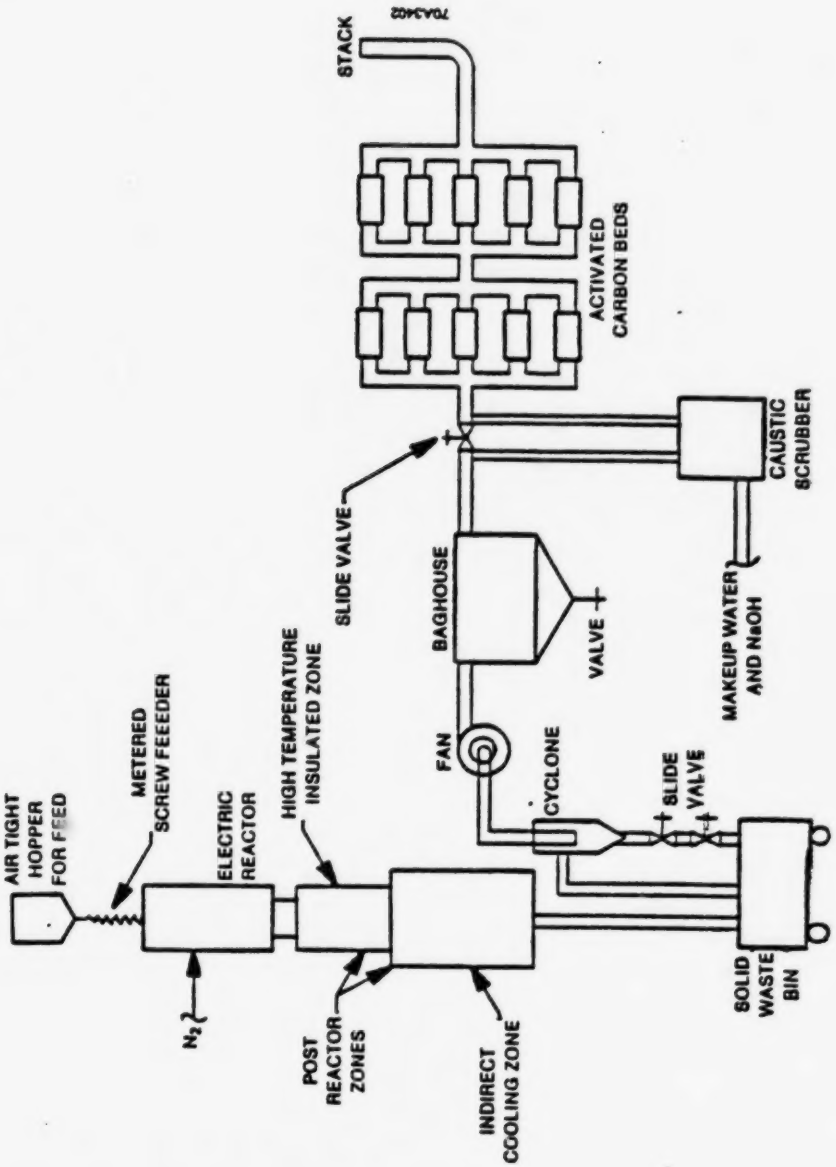


Figure 18. Process configuration for the test series. (From Lee et al., 1984).

Solids exiting the PRTZ are collected in a solids bin which is sealed to the atmosphere. Additional solids in the product gas are removed by a cyclone and routed back to the solids bin. The product gas then enters a baghouse for fine particle removal followed by an aqueous caustic scrubber for chlorine removal. Any residual organics and chlorine are removed by passing the product gas through activated carbon beds just upstream of the emission stack. The organic, particulate, and chlorine-free product gas composed almost entirely of nitrogen is then emitted to the atmosphere through the process stack.

III. ADVANTAGES

The developer states the following advantages:

1. Transportability.
2. Extremely high treatment efficiencies (because of the high process temperatures and long residence times).
3. Intrinsic safety features (such as the activated carbon beds, electrically driven solids feeder, and large amount of thermal inertia in the reactor).
4. Essentially no stack or fugitive emissions.
5. The ability to detoxify wastes in a pyrolytic atmosphere thereby avoiding products of oxidation such as dioxins and furans.

This technology has also demonstrated the ability to handle large volumes of soils on a continuous basis. In hazardous waste treatment, the HTG process is suited for the treatment of low-Btu-content hazardous materials (i.e., contaminated soils, pure PCBs, and other heavily halogenated hydrocarbons); extremely hazardous materials, such as dioxins, PCBs, and nerve gases; and in-process treatment of hazardous byproducts from chemical, metallurgical, and ceramic processes frequently with profitable raw materials recovery.

IV. OPERATING CONDITIONS

Form of Feed Materials:	Solid feed streams must generally be reduced to -35 U.S. mesh, and liquids must be atomized to no larger than 1500-micron droplets.
Temperature Range:	2200°-2760°C (4000°-5000°F)
Residence Time Range:	Variable, selected to obtain the desired destruction and removal efficiencies.
Energy Type and Requirements:	Electrical; 800-1000 kWh/ton Contaminated soils: 1500-2000 kWh/ton for complete dissociation of liquids.

V. PERFORMANCE TEST RESULTS

Extensive testing on the Advanced Electric Reactor is summarized in Tables 14-17. Typical behavior is in excess of 99.99999 destruction and removal efficiencies for polychlorinated biphenyls and 99.99999 for carbon tetrachloride.

The DRE results clearly demonstrate the extremely high treatment capabilities of the HTG AER process. No test yielded results below 99.9999 percent DRE. This is over two orders of magnitude better than RCRA minimum requirements for hazardous waste incinerators. Again, agreement between DREs calculated from the Huber results are supported by the Radian cross-checks and both support the previous statement of high AER treatment capability.

VI. COST ESTIMATES

For large-scale soil processing, estimates are from $300 and $600 per ton processed. The energy requirements for a normal soil are expected to be between 800 and 1200 kWh/ton varying with the temperature of the reaction and the moisture content of the soil.

VII. STATE OF DEVELOPMENT

Huber maintains two fully equipped Advanced Electric Reactors in Borger, Texas, as part of an over $4 million AER pilot facility. The smaller reactor, which has a nominal core diameter of 3 inches, is used for proof-of-concept

experiments. The larger reactor, which is of commercial scale, has a 12-inch core diameter but is used primarily for research purposes.

It is anticipated that by the second quarter of 1985 Huber will have a transportable 20,000 to 30,000 ton per year unit ready for the demonstration of treating dioxin-contaminated soil. A 50,000 ton per year unit can be available in early 1986 if applications are identified.

VIII. DEVELOPER INFORMATION

J. M. Huber Corporation
P. O. Box 2831
Borger, Texas 79007
(806) 274-6331

IX. REFERENCES

Headley, Kenneth N., Kenneth W. Lee, W. R. Schofield, and Larry T. Donovan. 1984. Parametric Study for the Destruction of Carbon Tetrachloride in the Huber Advanced Electric Reactor. Prepared for the Texas Department of Water Resources, Austin, Texas by the Huber Technology Group, 1100 Penn Avenue, Borger, Texas. June 22, 1984.

Lee, K. W., and D. S. Lewis. 1983. J. M. Huber PCB Destruction Process Trial Burn Report. Prepared for the J. M. Huber Corporation, 1100 Penn Avenue, Borger, Texas, October 31, 1983.

Lee, Kenneth W., William R. Schofield, and D. Scott Lewis. 1984. Mobile Reactor Destroys Toxic Wastes in "Space." Reprint from Chemical Engineering, April 2, 1984.

TABLE 14. PCB CONCENTRATIONS FOR PROCESS AND EMISSION STREAMS BY GC/MS

	Test 1 9/27/83	Test 2 9/28/83	Test 3 9/29/83	Test 4 9/29/83
Gas Streams (µg/SCM)				
Stack	0.23	0.03	0.10	0.30
Cyclone Outlet	4.1	4.1	21	2.4
Liquid Streams (µg/L)				
Scrubber Liquid	0.29	0.86	0.76	2.7
Pretest Scrubber Liquid	<0.14	NS	<0.14	<0.22
Scrubber Feed Water	<0.14	NS	NS	NS
Solid Streams (µg/g)				
Feed	2530	3100	2710[a]	2710
Treated Fed	0.0005	<0.0005	0.0006	0.001
Baghouse Filter Catch	0.024	0.29	NS	0.53[b]
Charcoal Bed (µg/g)	NS	NS	NS	0.001[c]
Pretest Charcoal (µg/g)	0.003	NS	NS	NS

Standard Conditions = 528°R, 1 atm.
NS = Not Sampled.
Values are not blank subtracted.

[a]Single feed batch used for Tests 3 and 4.

[b]Cumulative for Tests 3 and 4.

[c]Cumulative for Tests 1 and 4.

From Lee and Lewis, 1983.

TABLE 15. DESTRUCTION EFFICIENCIES AND DESTRUCTION AND REMOVAL EFFICIENCIES FOR PCBs

Parameters	Test 1	Test 2	Test 3	Test 4
Destruction Efficiency	99.99990	99.99992	99.9995	99.99995
Destruction and Removal Efficiency	99.999995	99.9999994	99.9999998	99.999993

From Lee and Lewis, 1983.

TABLE 16. CCl_4 CONCENTRATIONS FOR VARIOUS PROCESS STREAMS

Test No.	Feed (%)	Treated Material (µg/g)	Baghouse Filter Catch (µg/g)	Cyclone Outlet (µg/scm)		Cyclone Outlet (µg/scm)	
				Huber	Radian	Huber	Radian
1	1.24	0.69	--	0.03	0.02	0.002	0.0007
2	1.14	0.47	--	0.008	--	0.002	--
3	1.34	--	--	0.006	--	*	--
4	1.75	0.47	--	0.15	0.12	0.007	0.0004
5	--	--	--	0.05	--	<0.0002	--
6	--	--	--	0.01	--	0.0007	--
7	--	0.07	24.10	0.06	--	0.0004	--
8	0.28	0.14	4.20	0.008	0.008	0.002	0.001
9	0.46	--	--	0.004	0.004	<0.0009	<0.0007
10	--	0.56	1.33	0.0008	--	<0.0004	0.0007
11	--	--	--	0.003	--	<0.0004	--
12	--	--	--	0.02	--	<0.0004	--
13	--	--	--	<0.002	--	<0.0004	<0.0004
14	--	--	--	0.002	--	<0.0008	--
15	13.76	0.18	--	0.02	--	<0.0008	--
16	--	--	--	3300	--	0.005	--
17	--	--	--	5700	--	0.003	--

*The sampling pump failed while taking this sample.
-- = Not sampled.

From Headley et al., 1984.

TABLE 17. DESTRUCTION EFFICIENCIES (DE) AND DESTRUCTION REMOVAL EFFICIENCIES (DRE) FOR CCl_4

Test No.	DE	DRE
1	99.999920	99.999992
2	99.999956	99.999990
3	99.999908	*
4	99.999240	99.999963
5	99.999018	>99.999996
6	99.999749	99.999987
7	99.999296	99.999996
8	99.999914	99.999981
9	99.999922	>99.999983
10	>99.999952	>99.999961
11	99.999952	>99.999992
12	99.998355	>99.999961
13	>99.999873	>99.999965
14	99.999978	>99.999991
15	99.999916	>99.999997
16	98.3	99.999997
17	97.1	99.999999

*Sampling pump failed.

From Headley et al., 1984.

12.0 PLASMA SYSTEMS

Plasma Systems--processes that use the extremely high temperature of plasma to destroy waste materials. The plasma systems offer a very innovative approach to destroying highly toxic chemicals. Several systems have been researched. Two of these systems are discussed in the report.

The following processes are included:

Pyroplasma--Pyrolysis Systems, Inc.
Plasma Temperature Incinerator--Applied Energetics

I. TECHNOLOGY: Pyroplasma

DEVELOPER: Pyrolysis Systems, Inc.

II. PROCESS DESCRIPTION AND SCHEMATIC

In this plasma arc device, a co-linear electrode arrangement creates an electric arc which is stabilized by field coil medium through which an electric current is passed. As air passes the arc, the electrical energy is converted to thermal energy by adsorption by the air molecules which are activated into ionized atomic states, losing electrons in the process. Ultraviolet radiation is emitted when the molecules or atoms relax from their highly activated states to lower energy levels.

The resulting gas is in the plasma state consisting of charged and neutral particles with an overall charge near zero and with electron temperatures up to 28,000°C (50,000°F). As the activated components of the plasma decay, their energy is transferred to the waste materials exposed to the plasma; the wastes are ultimately decayed and destroyed.

A schematic of this process is shown in Figure 19.

III. ADVANTAGES

The developer states the following:

1. The process can handle highly toxic and refractory compounds.
2. Scale of equipment is small for high throughput rates.
3. Mobile configuration for capacities up to 1500 pounds per hour.
4. On/off cycle times of only a few minutes.

IV. OPERATING CONDITIONS

Form of Feed Materials: Highly toxic liquids

Temperature Range: Up to 28,000°C (50,000°F) electron temperature

Residence Time Range: 1 second

Energy Type and Requirements: Electrical.

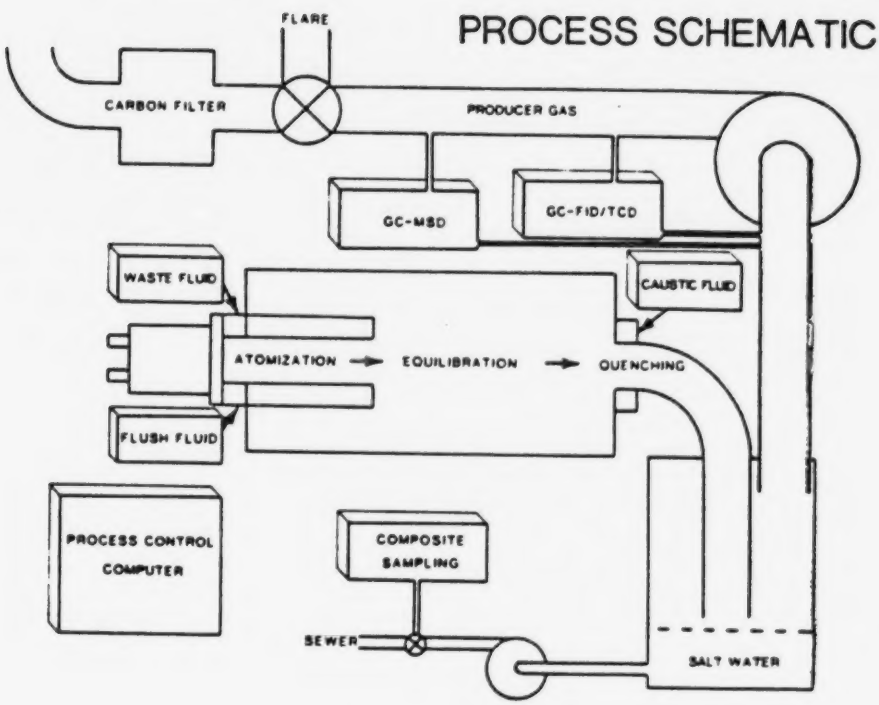


Figure 19. Pyroplasma process schematic.

V. PERFORMANCE TEST RESULTS

A pilot-size demonstration plant developed at the Royal Military College, Kingston, Ontario, has been used to gather data on the destruction of chlorinated organics, primarily PCBs. Destruction efficiencies in excess of 99.9999 percent were achieved, indicating that even greater destruction can be expected among the less stable chlorinated substances. The unit is sized to destroy approximately 500 lb/h of sludge, yet is designed to fit along with the necessary auxiliary equipment on a semitrailer. Commercial viability must be established by testing actual waste streams over an extended period on a continuous operating basis. For several years, Westinghouse Electric Corporation, Applied Plasma Systems, has been developing similar technology for application in industry processes. However, the heaters are equally applicable to hazardous waste destruction, and mobile units have been developed by Pyrolysis Systems, Inc., for field testing, using Westinghouse plasma heaters.

VI. COST ESTIMATES

Capital: $1.6 million for 1.5 MW mobile unit at 0.75 tons waste/hour.

Operating: Based on three-year cost recovery and up to 50 percent chlorination levels in the waste.

	2000 h/yr	6000 h/yr
	$0.9 - $2.1 million	$1.4 - $4.8 million
Total Per Unit of Feed:	$600 - $1400/ton	$300 - $1050/ton

VII. STATE OF DEVELOPMENT, MARKET POTENTIAL, RESEARCH NEEDS

The testing of this technology has been the subject of continuing support from the EPA and the New York Department of Environmental Conservation. The fabrication of a mobile unit capable of treating from 1 to 2-1/2 gallons per minute of waste was completed in the spring of 1984. A four-stage demonstration of this mobile unit is currently underway in Kingston, Ontario.

Market potential for mobile toxic and hazardous waste disposal systems is assessed by the developer as very good since the issue involving waste transportation and regional siting of larger facilities are eliminated and the impact of residual pollution to the adjacent community from the disposal facility is minimized.

Minor additional research needs are anticipated to verify suitable criteria for performance standards. In that continuous monitoring of the process is achieved by a series of GC-FID-TC and GC-MSD units onboard, guidelines must be established for suitable residual levels of product species. Producer gas is monitored to ppm levels, and residuals in the producer gas are monitored at ppt levels. The producer gas is subsequently flared after monitoring. A photograph of the unit being demonstrated is shown as Figure 20.

VIII. DEVELOPER INFORMATION

The Pyroplasma units are manufactured by Pyrolysis Systems, Inc., in Niagara Falls, Ontario.

Mr. Ian Thom
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Head Office is located in Welland, Ontario, and a branch office is located in Kingston, Ontario.

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Branch Office	Dr. T. G. Barton Pyrolysis Systems, Inc. 420 Carrie Crescent Kingston, Ontario, K7M 5X5 (613) 545-7395

Figure 20. Pyroplasma trailer in operation at Kingston, Ontario.

I. TECHNOLOGY: Plasma Temperature Incineration

DEVELOPER: Applied Energetics, Inc.

II. PROCESS DESCRIPTION AND SCHEMATIC

This incinerator burns the toxic waste including PCB in a pressurized stream of preheated oxygen. The operation can achieve temperatures of 2760°C (5000°F) and maintain them at elevated levels for periods up to 1 second. Figure 21 illustrates the major components of a stand-alone incinerator that is designed for a feed rate of 1900 liters per hour.

This plasma-incinerator system, as shown in Figure 21, contains a preheater, a combustion chamber, a reaction residence chamber, a quench chamber, a scrubber tower, and an exhaust stack. The preheater is a refractory-lined, water-cooled chamber in which a clean fuel is burned to preheat oxygen to about 1000°C (1800°F). The preheater consumes fuel at the rate of 120 kg/h to preheat 4.5 metric tons per hour of oxygen. The preheated oxygen enters the combustion chamber through a disperser plate. The disperser plate contains a number of fuel nozzles and oxygen ports, and it is designed to achieve optimal mixing of the two reactants. The temperature of the preheated oxygen is sufficient to auto-ignite any fuel when the heat of combustion is at least 14 kJ/g. This arrangement minimizes the risk of flameout and subsequent contamination of the area with partially burned toxic waste.

III. ADVANTAGES

The developer states the following:

1. In this plasma-temperature operating range, many molecules are highly disassociated and have free electrons that greatly increase their reactivity.

2. The combustion reaction rates have been shown to increase tenfold in some studies. In similar systems it has been shown that solid fuels were completely consumed in 35 to 50 milliseconds.

3. The higher combustion efficiencies that are achieved by this design yield a much more compact unit that will substantially reduce the cost of incineration. This unit can be built as a stand-alone

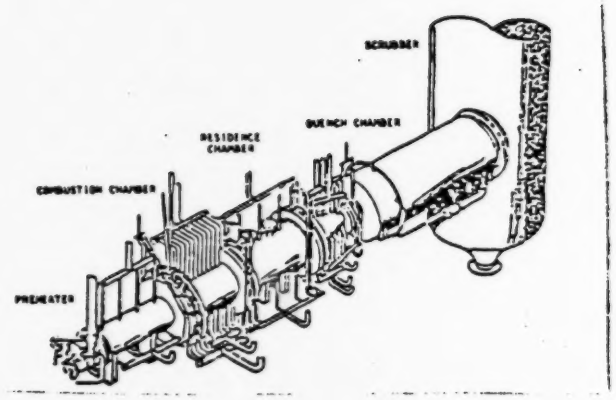

Figure 21. Plasma temperature incinerator.

incinerator, or it can be combined with heat recovery systems to conserve the energy that is released.

IV. OPERATING CONDITIONS

Form of Feed Material:	Liquids and fluidized solid wastes. Also preheated oxygen.
Temperature Range:	Up to 2760°C (5000°F)
Pressure Range:	6-9 atm.
Residence Time Range:	
Gas Phase:	Up to 0.3 second
Solid (or liquid) Phase:	Up to 1 second
Energy Type and Requirements:	Thermal, sensible heat to operating.

V. PERFORMANCE TEST RESULTS

A prototype of this system has been tested by a commercial waste treatment firm and performed to destroy PCB to within EPA standards.

VI. COST ESTIMATES

The cost of this incinerator system assembly for the 1900 liter-per-hour commercial-scale unit has been estimated at $3.2 million on a developed site. This cost includes all of the support facilities needed to operate the unit. Assuming that 75 percent of this cost can be financed at 18 percent interest and that the system will be depreciated over a 5-year period, then the bulk PCB waste can be destroyed for a cost of about $2.00 per gallon rather than the $6.00 per gallon that seems to be the going rate (Hollis, 1983).

Total Cost: $500/ton.

VII. STATE OF DEVELOPMENT

The design is complete; construction and testing of a commercial-size system has not yet begun.

VIII. DEVELOPER INFORMATION

Applied Energetics, Inc., is a Research and Design Company specializing in advanced energy development technology waste incineration and allied processes.

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IX. REFERENCES

Hollis, James R. 1983. Plasma Temperature Incineration. Environmental Progress, Vol. 2, No. 1, February 1983.